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Prepared for the National Aeronautics and Space Administration
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NASA Cooperative Agreement NCC 2-205

**UNIVERSITY OF CALIFORNIA, BERKELEY**

Progress Report
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# 1. INTRODUCTION

The Remote Sensing Research Program (RSRP) and NASA/ARC continue to enjoy cooperation on a wide variety of remote sensing related research topics. These topics include the study of new sensors, the design of experiments to test the applicability of satellite-derived spectral measurements, the development of software to facilitate the analysis of Landsat digital data and the continued experimentation with state- of-the-art microcomputers and computer networks for processing large spectral and geo-referenced data bases. Each of these areas is reported on in the following sections. Specifically,

Section 2 discusses results of research conducted with Thematic Mapper Simulator data to characterize selected soil properties and agricultural crops in San Joaquin County, California.

Section 3 describes the design of a Landsat-based multiple crop acreage estimation experiment for the Idaho Department of Water Resources including the use of U.C. Berkeley's Survey Planning Model.

Section 4 outlines progress made on Peditor software development on MIDAS, and cooperative computing using local and remote systems, and

Section 5 presents progress on the continuing development of the MIDAS microcomputer systems at UCB, USDA/Washington and NASA/ARC including increasing the reliability of the systems, integrating new systems, and experimenting with new components.

# 2. THEMATIC MAPPER SIMULATOR RESEARCH

## 2.1. Spectral Characterization of Selected Soil Properties Using Thematic Mapper Simulator Data

### 2.1.1. Introduction

The management of agricultural resources requires current information which is used by the agricultural resource specialist to formulate alternative management decisions on cultivation practices, irrigation scheduling and timing of harvest, among others. An important source of information used to formulate management alternatives is a soil resource inventory, or soil survey. A soil survey contains (usually in a narrative, graphical, map, and tabular format) the representations of soil individuals, or pedons. A cluster of soil individuals forms a polypedon, or soilscape. Soil mapping units are map polygons which form the working representation of the soilscapes, and these units are uniquely defined for each soil survey based on the objectives of the survey (5). The components of these mapping units are phases of soil series usually differentiated by major slope classes or other limitations to intensive agricultural production. The spatial estimation of soil properties is essential for conducting these soil surveys which form the basis of soil interpretations and management.

Remotely-sensed data and other environmental site variables have been used to characterize soil properties for soil surveys for many years. Since 1929 when the first soil survey was conducted with the aid of black-and-white panchromatic aerial photography, advancing aerospace technology has continued to provide soil surveyors with an important tool for stratifying natural landscapes into soil taxonomic units (6,16). The major regions of the electromagnetic spectrum used to conduct soil investigations range from the visible through the microwave. Several investigators have provided extensive reviews of remote sensing applications to soil science (7,11,19). The visible-photographic infrared region (0.400 um - 0.900 um) is used primarily in operational soil survey activities to characterize surface features which can be correlated to the subsurface soil profile properties required to classify soil individuals. These soil reflectance studies under field and controlled laboratory conditions have provided important information on those key soil properties governing the amount of radiation reflected from soil surfaces. These properties include soil color, soil moisture, organic matter, particle size distribution, iron oxides, and clay minerals (1,2,8,12,14,18,19).

A sensor which holds great promise for providing detailed, synoptic and repetitive data for soil resource investigations is the Thematic Mapper (TM) on-board the Landsat-4, and -5 spacecrafts. The TM data afford new opportunities for developing improved soil mapping methods using the shortwave infrared (SWIR) and thermal-infrared (TIR) regions of the spectrum. In order to evaluate the applicability of these data acquired by the TM sensor for soil survey, the nature and extent of the TM spectral variability resulting from key soil properties measured in situ needs to be determined.

Prior to the launch of the Landsat-4 spacecraft, NASA initiated a program where simulated Thematic Mapper data (TMS) would be acquired by the U-2 aircraft over selected areas to determine the usefulness of the increased spectral and spatial resolution of the TM sensor. Our objectives related to this TMS research mission were to: 1) quantify the spectral variability of two contrasting soils using the TMS spectral data; and 2) develop an understanding of the relationships between selected soil properties and their spectral response as measured by the TMS sensor from the visible to the thermal infrared regions of the spectrum.

## 2.1.2. Materials and Methods

### General Site Description

The general site was located in San Joaquin County, California (Figure 2.1). A mineral and an organic soil were selected for field sampling as they represent the major soils which support a variety of agricultural crops in the county. The fields selected for sampling were located in mapping units published in the existing survey for the county (20). The mineral soil sampled was the Escalon Series, and the organic soil sampled was the Rindge Series.

The Escalon Series is a member of the coarse-loamy, mixed, thermic family of Entic Haploxerolls. Escalon soils are found on low terraces with slopes less than 2 percent. The soils are formed from alluvium derived from granite rock sources. The climate is subhumid with hot, dry summers and cool, moist winters. Mean annual precipitation is 11 to 16 inches, the mean annual temperature is 60$^{o}$F, and the mean annual soil temperature varies from 62$^{o}$F to 63$^{o}$F. Escalon soils are moderately well-drained with slow runoff and moderately rapid permeability. They have depth to a duripan between 40 to 60 inches. In a typical profile, the surface layer (0-6 inches) is mildly alkaline, brown in color with strong, medium blocky clods. The surface soil is hard, very friable, non-sticky and non-plastic.

The Rindge Series is a member of the euic, thermic family of Typic Medisaprists. Rindge soils are layers of highly decomposed organic material that are over 60 inches thick. The soils are formed from hydrophytic plant remains

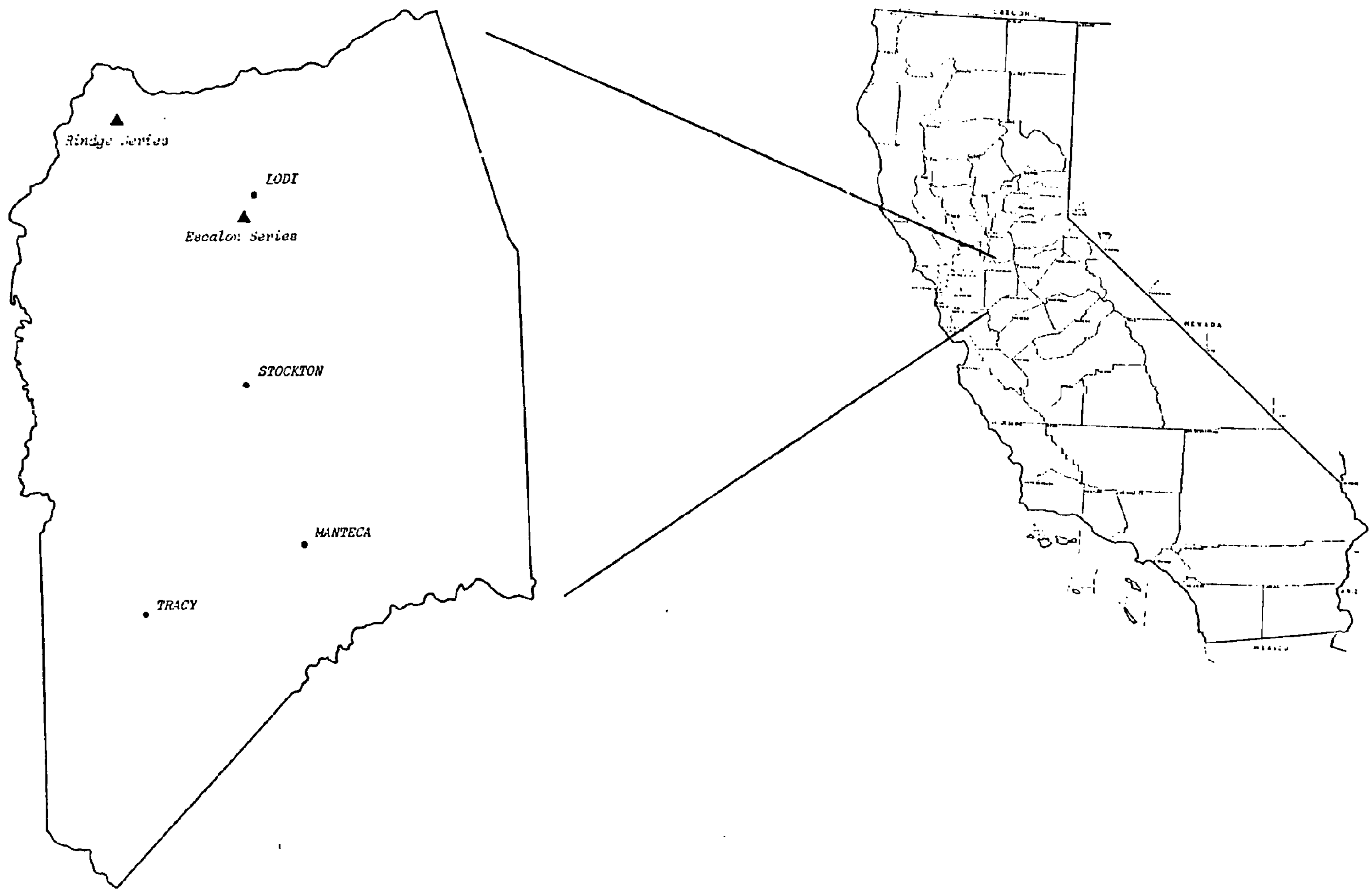



Figure 2-1. Location of the two field plots sampled coincidently with TMS Mission #82-114 over San Joaquin County, California.

and mixed mineral alluvium in fresh water marshes and river channels. The organic fraction is derived from reeds and tules and the mineral fraction is dominated by secondary clay minerals. The climate is Mediterranean with warm dry summers and cool winters. The mean annual precipitation is 14 to 16 inches. Mean annual temperature is approximately $60^{\circ}F$ and the mean annual soil temperature at a 20-inch depth is $60^{\circ}F$. These soils are usually very poorly drained with very slow runoff and rapid permeability. In the Delta area, the water table is lowered by artificial drainage with open drains and pumps. The water is usually at a depth of 36 inches during the growing season and at or near the surface at some time during the winter. In a typical profile, the surface layer is slightly acid, black sapric muck to about 36 inches. The underlying layer is a very dark brown, slightly acid, sapric muck extending to 60 inches or more.

## Field Sampling and Measurement Methods

The locations of the two field plots sampled are shown in Figure 2.1. Three subplots 20 meters apart were sampled in the Escalon Series and labeled A-1, A-2, and A-3. For the Rindge Series, the distance between 01-1 and 01-2 was 20 meters whereas 01-2 and 01-3 were 40 meters apart (Figure 2.2). The Escalon plot was located in a bare soil field whereas the Rindge plot was located in a field recently planted to corn. The corn plants at the time of sampling were 14cm in height with row spacing approximately 60cm in width.

The surface samples of the top 3cm of soil were collected at each sub-plot. For estimating the volumetric water content at the time of sampling, three separate subsamples were taken within a circle of 4 meters in diameter (Figure 2.2). Subsamples were collected in moisture cans, sealed with electric tape, kept in a cooler, brought to the laboratory, weighed, and oven dried at $105^{\circ}C$ for 48 hours. The average of the three subsamples was taken as a representative measure of water content at the time of sampling for each plot. All other data were based on a combined (mixed) sample at each of the three sub-plots. Moist and dry soil colors were determined in the field using the Munsell Soil Color Charts.

Soil surface temperatures were estimated using the Teletemp Infrared Thermometer (Model AG 42). Measurements were made using both the circular plot and line transect methods shown in Figure 2.3. For each soil sub-plot sampled for laboratory analysis, radiant surface temperatures and surface-ambient air temperature differences were recorded at eight look-directions from the center of the sub-plot. The target spot size was 0.05 meters in diameter. Radiant surface temperatures were measured in two additional fields for

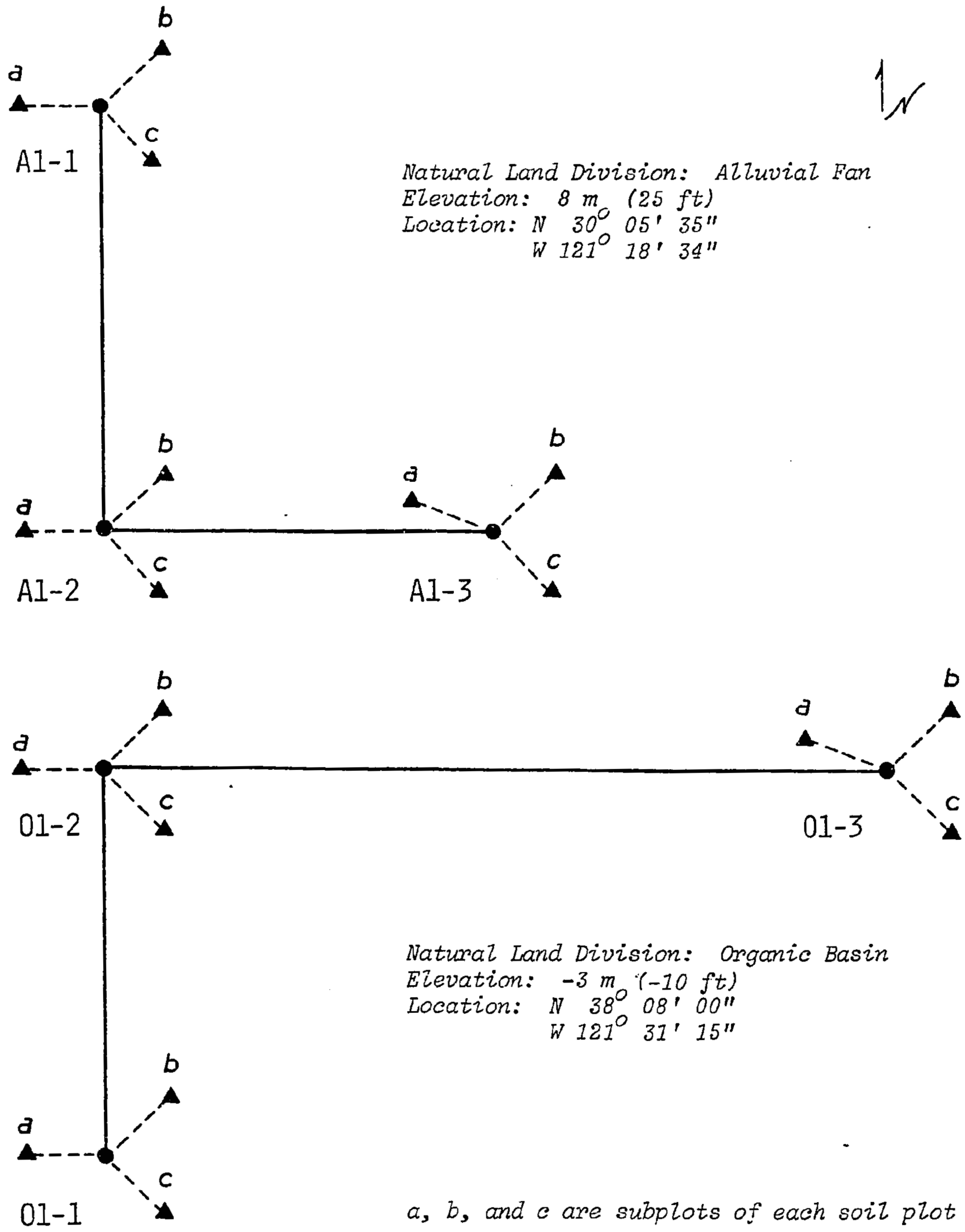
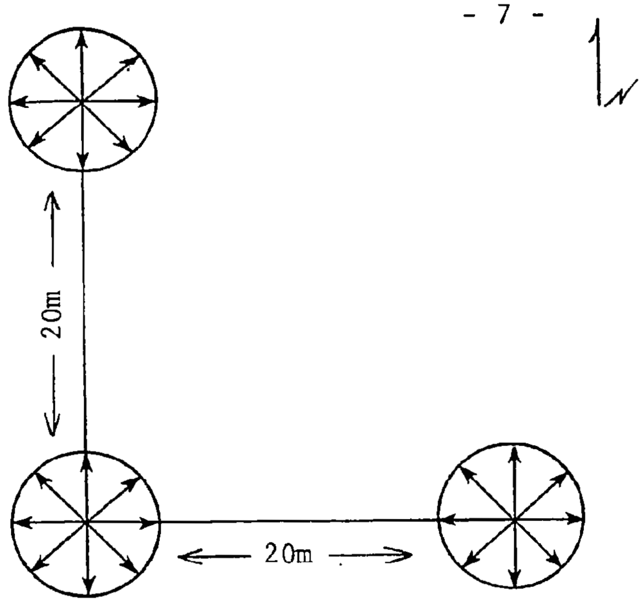
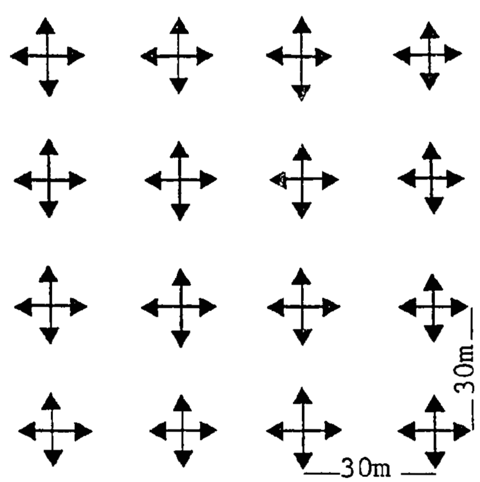



Figure 2-2. Field plot layout for sampling the Escalon Series (top) and the Rindge Series (bottom).




*CIRCULAR PLOT METHOD*




*LINE TRANSECT METHOD*

Figure 2-3. Circular plot (8 look directions) and line transect (4 look directions) methods for estimating the radiant surface temperature of the two bare soil fields, irrigated pasture and vineyard.

comparison with the TMS-acquired temperatures. One field was an irrigated pasture with standing water present in localized areas, and the other field was a vineyard with approximately 50% canopy cover. Individual measurements of the shaded and sunlit portions of the canopy were measured as well as the bare soil surface between the plants. These individual measurements were averaged to obtain the mean radiant surface temperature of the vineyard.

## Laboratory Analysis Procedures

Samples from each plot were analyzed in the Soil Morphology Laboratory at the University of California, Davis (UCD).

Soil samples were air dried, crushed with mortar and pestle, and passed through 2mm sieves. Gravel and stones larger than 2mm in diameter were reported as weight percentage of the total sample. Water content of air dry soil was calculated by oven drying samples at 105°C for 48 hours. Except for bulk density, organic carbon and organic matter analysis were made on soil material less than 2mm in diameter. All results were expressed on an oven dry basis.

Methods used to analyze the samples for selected properties are described briefly. Detailed descriptions are found in the Soil Morphology Laboratory Procedures Manual at UCD (9).

Particle Size Analysis: Sand fraction percentages were determined by the wet sieve method. A 100ml of 5% sodium hexametaphosphate solution was added to 10 grams of soil, shook overnight (about 15 hours), and washed through No. 300 mesh sieve. Material left in the sieve was oven dried at 105°C for 48 hours. The ovendried sand samples were poured in a nest of sieves with openings of 1, 0.5, 0.25, 0.1 and 0.05mm, and shook for 10 minutes. Material remaining in each sieve was weighed and the percentages of different sand sizes were calculated. Organic matter in the Rindge samples was removed prior to next sieving by burning the sample at 605°C for 24 hours.

Clay: Fraction percentages were determined by the clod method. For the mineral soils (Escalon), four clods of each soil sample were air dried, weighed, coated with parafin and immersed in water of density 1gm/cc. Calculations were made according to the weight differences in air and immersed samples. The same procedure was followed for the organic soils (Rindge) but since these soils float in water, bulk densities were calculated by measuring the volume of displaced water. In both cases a sub-sample of each clod was taken, ovendried at 105°C for 48 hours. Calculations were made on the oven dry weight as an average of the four clods for each soil plot.

Organic Carbon: Soil samples of 0.05 to 0.2gm were passed through an 80 mesh sieve, and placed in crucibles. Copper metal, 0.5gms, and iron, 4gms, were added to each sample as accelerators (or catalysts) to insure complete combustion of the organic matter and elemental carbon. The crucibles were put in a combustion chamber and burned at 350°C for 1.5 minutes. Carbon dioxide gas was collected and weighed.

Organic Matter: The organic matter percentage was calculated by multiplying percent organic carbon by a factor of 1.9 (3,4).

Percent Moisture at Saturation: Water was added to the soil samples and percent moisture was calculated according to the amount of water needed to achieve a saturation paste.

Reaction: Soil reaction, expressed as a pH value, was obtained by glass electrodes using a saturated paste which was mixed 24 hours previously.

Electrical Conductivity: Electrical conductivity (EC) is used to estimate the soluble salts in the saturation extract. EC was determined by using a wheatstone bridge, and is recorded in mmhos/cm at 25°C.

Moisture retention (1/3 and 15 atmospheres): These values were determined by the pressure cooker method. Soil samples were placed in 1cm rubber retaining rings on a porous ceramic plate. Water was added to the samples, and the samples were allowed to soak overnight. The plate and the soil samples were then put in the pressure cooker apparatus. Equilibrium for the 1/3 bar was reached after 8 hours, and after 24 hours for the 15 bar equilibrium. Soil samples were removed, weighed, and oven dried for calculating the amount of water retained at both 1/3 and 15 bar.

## Spectral Data Acquisition and Processing

Multispectral data using the Thematic Mapper Simulator (TMS) were acquired over San Joaquin County, California as part of U-2 Mission #82-114, which is documented in Flight Summary Report (FSR) #1621 (15). Table 2.1 lists the spectral regions acquired, and the sensor/aircraft parameters used for this mission.

The spectral data were provided by NASA-Ames Research Center in the form of 8-bit digital records for each TM Band for the portion of one flight line containing our sampled fields. The digital data were reformatted and a file created on the RSRP image analysis computer system. The physical

## I. SPECTRAL REGIONS

| Daedalus Channel | TM Band | Wavelength um |
|---|---|---|
| 1 | A | 0.42 - 0.45 |
| 2 | 1 | 0.45 - 0.52 |
| 3 | 2 | 0.52 - 0.60 |
| 4 | B | 0.60 - 0.62 |
| 5 | 3 | 0.63 - 0.69 |
| 6 1 | C | 0.69 - 0.75 |
| 7 | 4 | 0.76 - 0.90 |
| 8 | D | 0.91 - 1.05 |
| 9 | 5 | 1.55 - 1.75 |
| 10 | 7 | 2.08 - 2.35 |
| 11 | 6 (low gain) | 10.4 - 12.5 |
| 12 | 6 (high gain) | 10.4 - 12.5 |

## II. SENSOR/AIRCRAFT PARAMETERS:

| | |
|---|---|
| IFOV: | 1.3 mr |
| Nominal Ground Resolution: | 28 m @ 70,000 feet altitude |
| Actual Ground Resolution: | 24 m across track<br>17 m along track |
| Area/Pixel: | 0.041 ha |
| Total scan angle: | $43^{0}$ |
| Date: | 22 June 1982 |
| Time of acquisition over field plots: | 1150 hours (PDT) |

Table 2-1. Spectral regions acquired by the TMS sensor over San Joaquin County, California on June 22, 1982.

dimension of the file was 316 x 202 pixels for each area sampled. Rescale constants and calibration values from the FSR were also added to the file so the 8-bit digital count (DC) values could be converted to spectral radiance and temperature values, respectively. Figure 2.4 shows the plot of the blackbody calibration sources used to convert the digital count values to radiant temperatures for the fields sampled.

Geometric processing of the digital data included the location and processing of 19 control points distributed throughout the area covered by the file. Using a linear, least-squares regression algorithm, coefficients were calculated to use in a bi-variate second order polynomial for predicting the pixel location of our field plots in the spectral data file. Based on the pixel location calculated, values for a 3 x 3 matrix of pixels surrounding the predicted plot location was extracted from the file for statistical analysis. Statistics calculated include means, standard deviations, coefficients of variation, frequency histograms, and covariance and correlation matrices for each of the two bare soil plots, the irrigated pasture, and the vineyard.

## 2.1.3. Results and Discussion

### Soil Property Characterization

The results of the laboratory analyses for both the Escalon and Rindge Series are shown in Table 2.2. The major soil properties that influence reflectance are considered to be surface color, texture (including particle size distribution), moisture content at time of sampling and the amount of organic matter.

The Escalon Series had very dark grayish brown (10 YR 3/2) moist colors and brown (10 YR 5/3) dry colors. Surface soil colors of the Rindge Series were black (10 YR 2/1) moist and dark grayish brown (10 YR 4/2) when dry. Based on the water content values in Table 2.2, the soil colors at the time of sampling correspond to the dry values.

The upper 4cm that were sampled in the three plots of the Escalon Series had fine sandy loam textures. The total sand in A1-1, A1-2, and A1-3 ranged between 63.07 to 65.27 percent of the total soil less than 2mm. Fine sand averaged 21.96 percent, very fine sand 15.63 percent, medium sand 13.68 percent and coarse sand 1.97 percent. Very coarse sand was found in minor amounts and formed 1.68 percent of the total. The silt fraction ranged from 19.00 percent to 21.06 percent in the three studied sites of the Escalon Series and it averaged about 20 percent of the total soil. The total clay fraction ranged between 15.01 to 16.47 percent and

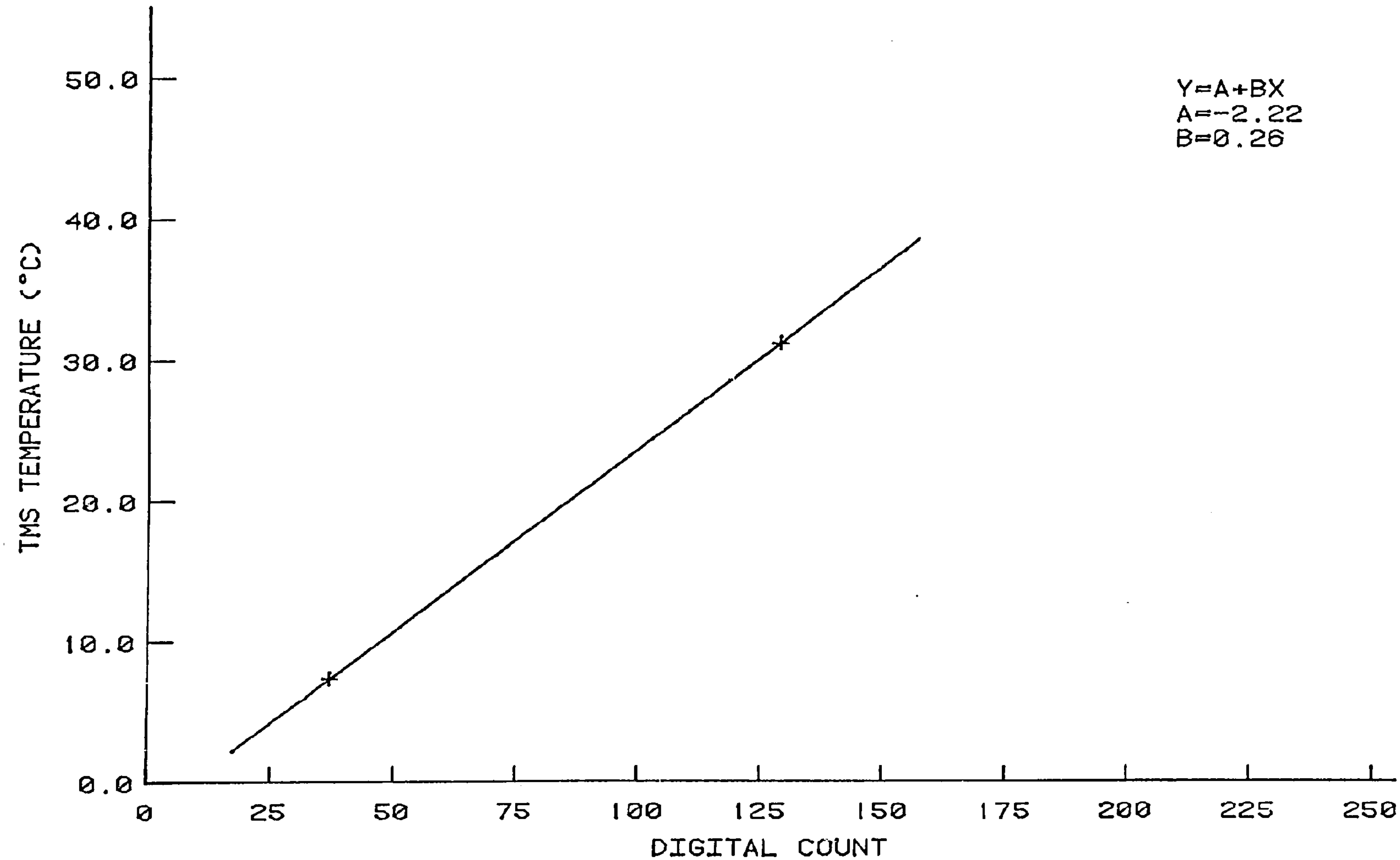



Figure 2-4. Plot of two on-board black body calibration sources used to convert digital count values to radiant temperatures.

| Sample No. | Depth (in.) | Color Moist | Color Dry | Gravel | Particle Size Distribution (PSD) % Sand VCS | CS | MS | FS | VFS | TOTAL | % Silt | % Clay 1-2μ | <1μ | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1-1 | 0-1.5 | 10YR 3/2 | 10YR 5/3 | ~0 | 2.02 | 12.31 | 13.62 | 22.19 | 15.13 | 65.27 | 19.00 | 8.63 | 7.10 | 15.73 |
| A1-2 | 0-1.5 | 10YR 3/2 | 10YR 5/3 | ~0 | 1.21 | 11.80 | 13.21 | 21.78 | 15.93 | 63.93 | 21.06 | 8.41 | 6.60 | 15.01 |
| A1-3 | 0-1.5 | 10YR 3/2 | 10YR 5/3 | ~0 | 1.82 | 11.81 | 12.41 | 21.9 | 15.84 | 63.07 | 20.46 | 9.10 | 7.37 | 16.47 |
| | | | | $\bar{x}$= | 1.68 | 11.97 | 13.08 | 21.96 | 15.63 | 64.09 | 20.17 | 8.71 | 7.02 | 15.74 |
| | | | | sd= | 0.42 | 0.29 | 0.62 | 0.21 | 0.44 | 1.11 | 1.06 | 0.35 | 0.39 | 0.73 |
| | | | | CV= | 25.1 | 2.4 | 4.7 | 1.0 | 2.8 | 1.7 | 5.3 | 4.0 | 5.6 | 4.6 |
| 01-1 | 0-1.5 | 10YR 2/1 | 10YR 4/2 | ~0 | 0.11 | 1.96 | 4.47 | 7.41 | 4.47 | 18.42 | 26.7 | 31.7 | 23.18 | 54.88 |
| 01-2 | 0-1.5 | 10YR 2/1 | 10YR 4/2 | ~0 | 0.22 | 1.85 | 7.95 | 10.99 | 4.25 | 25.26 | 20.81 | 30.57 | 23.36 | 53.93 |
| 01-3 | 0-1.5 | 10YR 2/1 | 10YR 4/2 | ~0 | 0.22 | 1.41 | 2.17 | 3.59 | 4.13 | 11.52 | 30.71 | 32.99 | 24.78 | 57.77 |
| | | | | $\bar{x}$= | 0.18 | 1.74 | 4.86 | 7.33 | 4.28 | 18.40 | 26.07 | 31.75 | 23.77 | 55.53 |
| | | | | sd= | 0.06 | 0.29 | 2.91 | 3.70 | 0.17 | 6.87 | 4.98 | 1.21 | 0.88 | 2.00 |
| | | | | CV= | 34.6 | 16.7 | 59.8 | 50.5 | 4.0 | 37.3 | 27.1 | 3.8 | 3.7 | 3.6 |

Table 2-2. Physical and chemical laboratory analyses results for both the Escalon (A1-) and Rindge (01-) soil samples.

| Sample No. | PSD Texture | Bulk Density g/cc | Moisture Retention Data %Moisture at Saturation | %Moisture at Sampling | %Moisture Retained 1/3 atm. | 15 atm. | %Available Moisture | pH | $ECx10^3$ mmhos/cm | %organic carbon | %organic matter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Al-1 | fsl | 1.69 | 22.34 | 0.70 | 13.6 | 3.3 | 10.3 | 7.8 | 1.16 | 0.77 | 1.46 |
| Al-2 | fsl | 1.68 | 21.22 | 0.66 | 12.9 | 3.4 | 9.5 | 7.7 | 0.97 | 0.86 | 1.62 |
| Al-3 | fsl | 1.73 | 21.19 | 0.66 | 13.8 | 3.5 | 10.3 | 7.8 | 0.84 | 0.82 | 1.56 |
| | $\bar{x}$= | 1.70 | 21.58 | 0.67 | 13.4 | 3.4 | 10.0 | 7.8 | 0.99 | 0.82 | 1.55 |
| | sd= | 0.03 | 0.66 | 0.02 | 0.5 | 0.1 | 0.5 | 0.1 | 0.16 | 0.05 | 0.08 |
| | CV= | 1.6 | 3.0 | 3.4 | 3.7 | 2.9 | 5.0 | 1.3 | 16.3 | 5.5 | 5.2 |
| 01-1 | sapric | 0.93 | 91.04 | 6.01 | 65.8 | 33.8 | 32.0 | 6.3 | 1.49 | 13.81 | 26.24 |
| 01-2 | sapric | 0.94 | 85.00 | 6.65 | 60.3 | 30.9 | 29.4 | 6.3 | 1.41 | 14.39 | 27.33 |
| 01-3 | sapric | 0.91 | 89.12 | 6.42 | 62.7 | 32.9 | 29.8 | 6.1 | 1.24 | 13.69 | 26.01 |
| | $\bar{x}$= | 0.93 | 88.39 | 6.36 | 62.9 | 32,53 | 30.4 | 6.23 | 1.38 | 13.96 | 26.58 |
| | sd= | 0.02 | 3.09 | 0.32 | 2.76 | 1.48 | 1.40 | 0.12 | 0.13 | 0.37 | 0.68 |
| | CV= | 1.6 | 3.5 | 5.1 | 4.4 | 4.6 | 4.6 | 1.9 | 9.3 | 2.7 | 2.6 |

Table 2-2 (con't). Physical and chemical laboratory analyses results for both the Escalon (Al-) and Rindge (01-1) soil samples.

averaged 15.74 percent. The clay fraction between 1 u - 2 u averaged 8.71 percent whereas that fraction less than 1 u formed 7.02 percent.

The Rindge Series was sapric in the upper 4cm. The mineral fraction was dominated by clay which averaged 55.53 percent of the total. Out of this fraction, clay of size between 1 u and 2 u formed 31.75 percent and that fraction less than 1 u amounted to 23.77 percent. The sand fraction averaged 18.40 percent of which fine sand formed 7.33 percent, medium sand 4.86 percent, very fine soil 4.28 percent whereas coarse and very coarse sand formed 1.74 percent and 0.18 percent respectively. The average silt fraction of the three sites in the Rindge Series averaged 26.07 percent.

The three sites in the Escalon Series A1-1, A1-2, and A1-3 had a moisture content at time of sampling that ranged between 0.66 to 0.70 percent by weight with an average of 0.67 percent. The Rindge Series sites had a moisture content at time of sampling that ranged between 6.01 percent to 6.65 percent with an average of 6.36 percent. This difference was mostly due to the high water holding capacity in addition to the clay fraction dominating the mineral fraction of this soil. In contrast, the Escalon Series has a sand fraction dominating the particle size distribution resulting in a relatively low water holding capacity.

The Escalon Series is a mineral soil low in organic matter. The average organic matter in all the three sites A1-1, A1-2 and A1-3 was 1.55 percent. Conversely, the Rindge Series is an organic soil with a sapric surface horizon and an average organic matter content of approximately 27 percent. These laboratory data compare favorably with results from other investigations and surveys (10,13,17,21).

## Infrared Thermometry

The purpose of acquiring ground-based temperature measurements was to provide a measure of the correlation between soil and plant radiant temperatures as recorded by the TMS scanner and ground observation. If high, positive correlation exists, the scanner data could be used to more efficiently and accurately measure these temperatures over large areas. The use of soil and plant temperatures aid in the mapping of soils for taxonomic purposes. Table 2.3 summarizes the environmental conditions prevalent at the time of the overpass. The wind speed at both sites was significant to cause some of the variabilty witnessed in the scanner data when compared to ground observations. Table 2.4 summarizes a subset of the surface radiant temperatures measured using the Teletemp Infrared Thermometers. The effect of look direction on remotely sensed surface radiant temperatures can be evaluated with this data set for two

| | Escalon | | Rindge |
|---|---|---|---|
| Date: 6/22/82 | Bare Soil | Vineyard | Bare Soil |
| Time (hours) | 1200 | 1210 | 1446 |
| Air temperature ($^{o}C$) | 22.8 | 24.4 | 27.9 |
| Wet bulb temperature ($^{o}C$) | 17.8 | 19.2 | 20.2 |
| Relative Humidity (%) | 61 | 63 | 48 |
| Wind Speed (m/sec) | 3.6 | 1.4 | 3.9 |

Table 2-3. Meteorological and environmental conditions at the time of sampling the Escalon and Rindge Series.

| Escalon Series | | | | | | Look Direction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | E | N | NE | E | SE | S | SW | W | NW | $\bar{x}$ | s |
| A1-1 | .99 | 39.5 | 38.0 | 38.0 | 36.2 | 36.8 | 36.2 | 39.5 | 39.5 | 37.9 | 1.4 |
| A1-2 | .99 | 40.5 | 38.6 | 38.3 | 38.3 | 39.5 | 39.0 | 37.7 | 41.5 | 39.2 | 1.3 |
| A1-3 | .99 | 39.5 | 38.5 | 39.4 | 38.4 | 37.3 | 38.2 | 40.2 | 40.7 | 39.0 | 1.1 |

| Rindge Series | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-1 | .99 | 48.6 | 47.2 | 45.1 | 48.9 | 50.5 | 44.5 | 46.7 | 48.6 | 47.5 | 2.0 |
| 01-2 | .99 | 47.3 | 49.0 | 48.8 | 45.6 | 48.9 | 48.8 | 50.4 | 48.5 | 48.4 | 1.4 |
| 01-3 | .99 | 48.2 | 48.8 | 46.5 | 50.8 | 49.4 | 49.6 | 50.5 | 49.7 | 49.2 | 1.4 |

Table 2-4. Surface radiant temperatures for the Escalon Series (top) and the Rindge Series (bottom) measured at each subplot for both soils using the circular plot method.

contrasting types of soils. This analyses has not been conducted on these data as of this date. There is a significant difference in the relative magnitudes of radiant temperatures measured for the two soils. This results from the combined effects of organic matter content, soil moisture and time of sampling. The Rindge soil exhibits uniformly warmer temperatures due to the higher organic matter content and to the later time period of sampling (See Table 2.3).

TMS Spectral Data

The geometric control point processing of the TMS spectral data allowed prediction of our true ground sampling location within 0.91 pixel (24.12m) RMS across-track and 0.73 pixel (17.24m) RMS along-track. The pixel dimensions for this TMS mission correspond to 24.03m across-track and 17.24m along track for a pixel area of approximately 414.28m$^2$ (0.0414ha). This represents a ground resolution larger than the true TM resolution of 30m (28.5m, resampled), and an oversampling of points in the along-track dimension. These differences in the geometric quality of the TM and TMS data are insignificant, and do not adversely impact the analysis of the spectral data for meeting our soil taxonomy objectives.

The mission was not completely successful in acquiring spectral data for both ground sample sites. The Escalon Series site was spectrally sampled during one flight line, but a scanner malfunction during the next flight line prohibited the spectral sampling of the Rindge Series site. The lack of multispectral data for the Rindge Series site is significant, and prohibits a rigorous statistical analysis of the data. To extract as much information as possible from the mission and to capitalize on the ground data collected, a substitute site in the eastern-most portion of the Rindge mapping unit was selected for spectral data extraction and analysis. This portion of the mapping unit was imaged on the same flight line as that which imaged the Escalon Series. As agronomic, pedologic and climatic conditions were very similar in this portion of the mapping unit, interpretation of the statistical data and spectral plots should provide adequate information for determining the effect of organic soil properties on spectral response.

The data for all spectral bands operating during the TMS mission for our two sites are shown in Table 2.5. The data have been converted to spectral radiance and temperature values based on the constants provided in the Flight Summary Report. The data tabulated includes means, standard deviations and CV's for each site for each spectral band. The magnitudes of the spectral radiance for the Escalon and Rindge Series are significantly different in TMS Bands 3 and 4 due to the differences in the organic matter content. Differences in the spectral radiance magnitude in TMS Bands 4 and 7 result from particle size distribution and moisture,

| Daedalus Channel | TM Band | Wave Length (μm) | Escalon Series | | | | Rindge Series | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Cover | $\bar{x}$* | sd | CV | $\bar{x}$* | sd | CV |
| 1 | A | 0.42-0.45 | Bare Soil | 8.88 | 0.97 | 10.9 | | | |
| | | | Pasture | 7.56 | 0.58 | 7.7 | 7.18 | 0.49 | 6.8 |
| | | | Vineyard | 7.63 | 0.43 | 5.6 | | | |
| 2 | 1 | 0.45-0.52 | Bare Soil | 8.62 | 0.10 | 1.2 | | | |
| | | | Pasture | 6.52 | 0.12 | 1.8 | 6.92 | 0.08 | 1.2 |
| | | | Vineyard | 6.92 | 0.09 | 1.3 | | | |
| 3 | 2 | 0.52-0.60 | Bare Soil | 9.46 | 0.06 | 0.6 | | | |
| | | | Pasture | 6.51 | 0.11 | 1.7 | 6.50 | 0.11 | 1.7 |
| | | | Vineyard | 6.89 | 0.09 | 1.3 | | | |
| 4 | B | 0.60-0.62 | Bare Soil | 9.52 | 0.12 | 1.3 | | | |
| | | | Pasture | 5.52 | 0.30 | 5.4 | 5.90 | 0.13 | 2.2 |
| | | | Vineyard | 6.25 | 0.08 | 1.3 | | | |
| 5 | 3 | 0.63-0.69 | Bare Soil | 9.50 | 0.07 | 0.7 | | | |
| | | | Pasture | 4.99 | 0.07 | 1.4 | 5.51 | 0.12 | 2.2 |
| | | | Vineyard | 6.03 | 0.12 | 2.0 | | | |
| 6 | C | 0.69-0.75 | Bare Soil | 8.94 | 0.05 | 0.6 | | | |
| | | | Pasture | 8.40 | 0.16 | 1.9 | 5.19 | 0.09 | 1.7 |
| | | | Vineyard | 7.49 | 0.11 | 1.5 | | | |
| 7 | 4 | 0.76-0.90 | Bare Soil | 8.05 | 0.06 | 0.7 | | | |
| | | | Pasture | 8.11 | 0.24 | 3.0 | 4.96 | 0.08 | 1.6 |
| | | | Vineyard | 7.18 | 0.14 | 1.9 | | | |
| 8 | D | 0.91-1.05 | Bare Soil | 4.58 | 0.05 | 1.1 | | | |
| | | | Pasture | 3.43 | 0.23 | 6.7 | 3.39 | 0.07 | 2.1 |
| | | | Vineyard | 3.94 | 0.09 | 2.3 | | | |
| 9 | 5 | 1.55-1.75 | Bare Soil | 2.06 | 0.07 | 3.4 | | | |
| | | | Pasture | 0.65 | 0.05 | 7.7 | 1.27 | 0.04 | 3.1 |
| | | | Vineyard | 1.32 | 0.05 | 3.8 | | | |
| 10 | 7 | 2.08-2.35 | Bare Soil | 1.26 | 0.01 | 0.8 | | | |
| | | | Pasture | 0.25 | 0.02 | 8.0 | 0.80 | 0.02 | 2.5 |
| | | | Vineyard | 0.65 | 0.02 | 3.1 | | | |
| 12 | 6 | 10.4-12.5 | Bare Soil | 38.25 | 1.00 | 2.6 | | | |
| | | | Pasture | 23.97 | 0.90 | 3.8 | 38.63 | 0.78 | 2.0 |
| | | | Vineyard | 37.21 | 1.04 | 2.8 | | | |

* mean radiance value ($mW/cm^2 \cdot \mu m \cdot sr$) for Daedalus Channels 1-10; and $^0C$ for Daedalus Channel 12

Table 2-5. Means, standard deviations and CV's, by Daedalus channels, for each of the covers that were field checked.

respectively. These data are graphically displayed in Figures 2.5 and 2.6. In Figure 2.5 the two significant properties of curve shape and curve magnitude illustrate the major soil properties affecting the amount of spectral radiance from the soil surface. The Escalon Series is dominated by a coarse texture, low organic matter content, low moisture, and relatively high surface roughness. These properties combine to yield radiance curves which have a relatively high magnitude and convex shape (19). The Rindge Series is dominated by a high organic matter content, high moisture content and relatively low surface roughness. These properties combine to yield radiance curves which have a low magnitude and concave shape (19). The curves represented in Figure 2.5 for both soils display these characteristics very well. This preliminary finding indicates that the location and width of the TM spectral bands are adequate for the detection, identification, and mapping of soil properties important to soil survey and management activities.

In Figure 2.6, the spectral data for the irrigated pasture and vineyard have been added showing the characteristic high infrared reflectance in TM Band 4 and strong absorption in the SWIR bands due to high leaf water content. In addition, the surface radiant temperatures measured by Band 6 for all sites are plotted in Figures 2.5 and 2.6. The temperature value for the Escalon-pasture is significantly different from the other sites due to the standing water in the pasture. The evaporative cooling effect of the water reduces the radiance temperature of the field, a temperature which is detectable and measurable with the high spectral and spatial quality of the TMS data.

The relative redundancy of the TM spectral bands for detecting soil properties was determined by evaluating band to band correlations for the two soils. In Table 2.6, seven interband correlation coefficients for the TMS data for the Escalon and the Rindge Series are summarized. Differences in soil properties dictate the relative magnitudes of these interband coefficients. For inorganic, coarse textured soils low in organic matter, Bands 3, 4, 5 and 7 provide the best subset of bands for soil survey properties based on minimum interband correlation. For the high organic matter and high moisture-content soils, all bands provide useful information especially when the visible and the SWIR bands are used in combination. High interband correlations (>0.70) are indicative of band redundancy and are evident in Table 2.6 for Bands 2 and 3 (organic soil), Bands 3 and 4 (organic soil), and Bands 1 and 2 (inorganic soil). If selection of a subset of bands is necessary to reduce the amount of processing, or to improve one's ability to map selected soil properties, careful consideration of these interband correlation coefficients is advised.

The relationship between the surface radiant

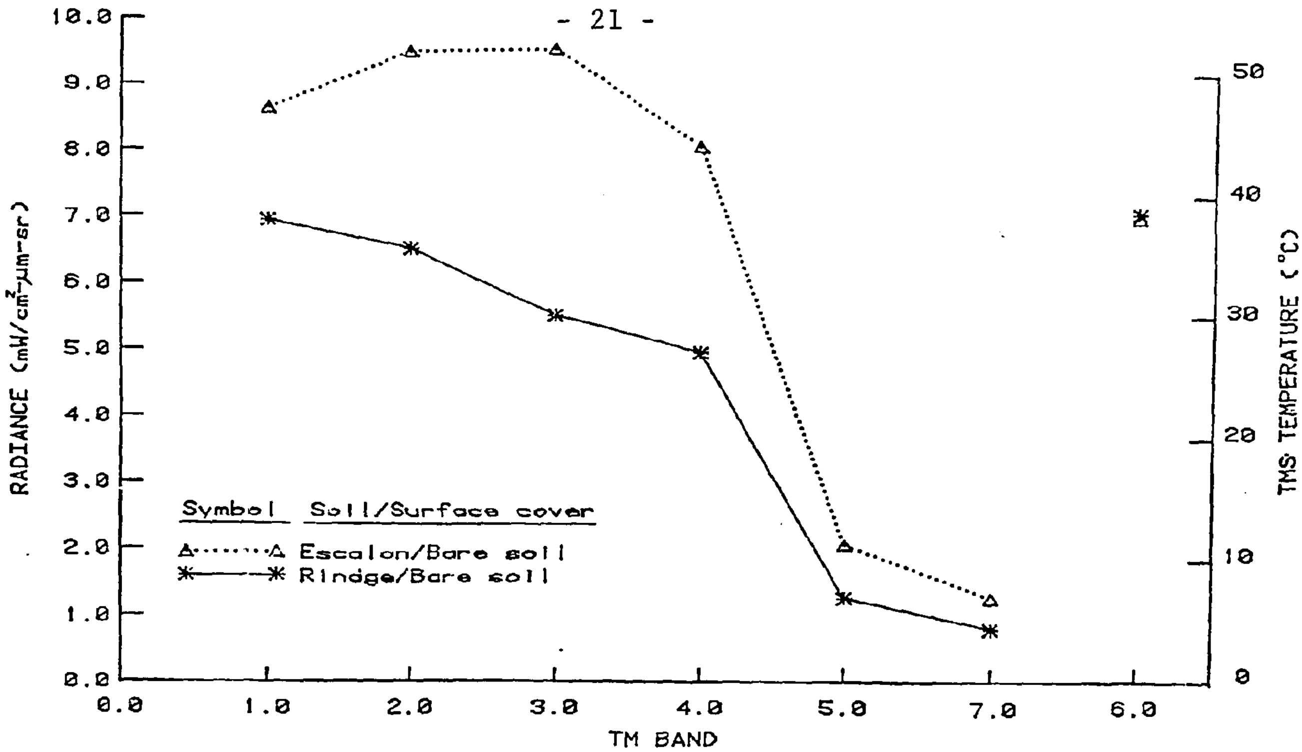



Figure 2-5.

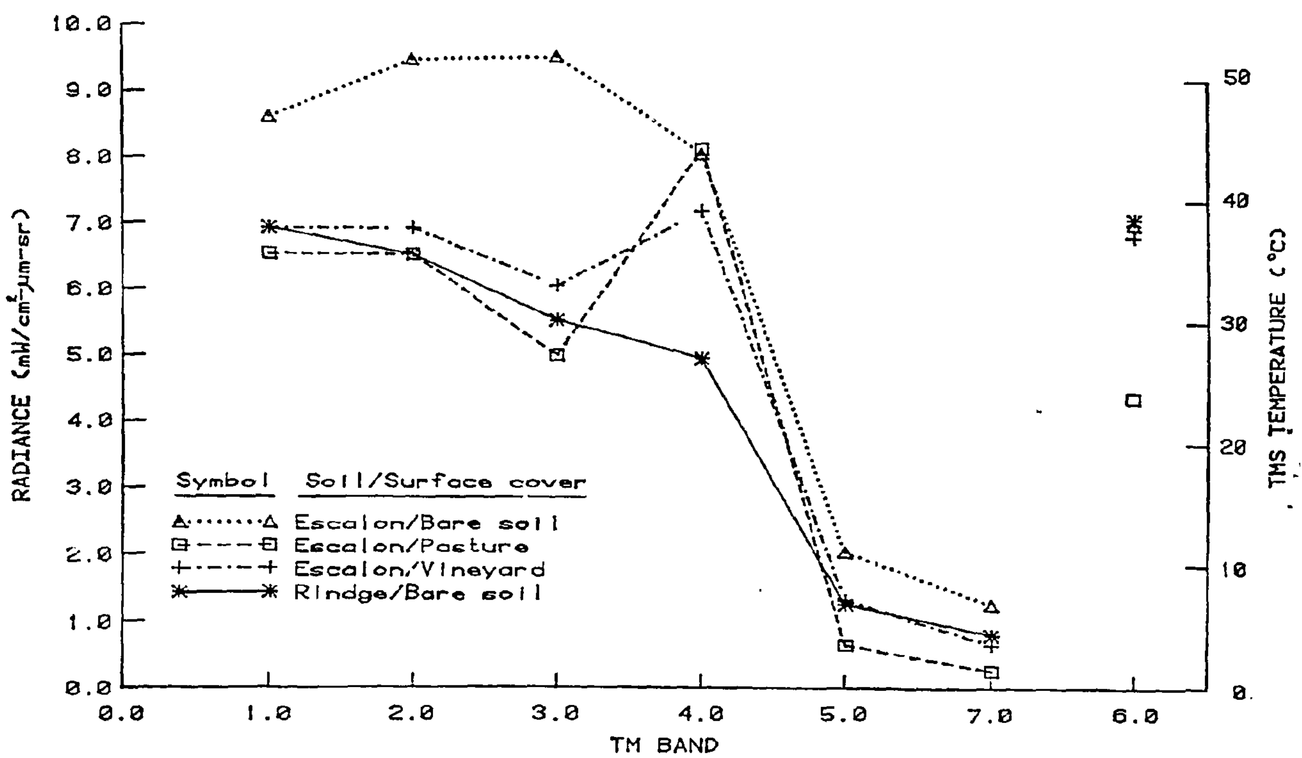



Figure 2-6.

| | TMS1 | TMS2 | TMS3 | TMS4 | TMS5 | TMS7 |
|---|---|---|---|---|---|---|
| TMS1 | | | | | | |
| TMS2 | 0.725(E)<br>0.652(R) | | | | | |
| TMS3 | 0.655(E)<br>0.621(R) | 0.578(E)<br>0.856(R) | | | | |
| TMS4 | 0.584(E)<br>0.423(R) | 0.599(E)<br>0.642(R) | 0.177(E)<br>0.717(R) | | | |
| TMS5 | 0.688(E)<br>-0.087(R) | 0.566(E)<br>0.076(R) | 0.277(E)<br>0.150(R) | 0.580(E)<br>0.194(R) | | |
| TMS7 | 0.414(E)<br>0.426(R) | 0.496(E)<br>0.547(R) | 0.659(E)<br>0.572(R) | -0.280(E)<br>0.503(R) | 0.118(E)<br>0.078(R) | |

Table 2-6. Summary of the seven interband correlation coefficients for the Thematic Mapper Simulator data. (E) = Escalon Series, (R) = Rindge Series.

temperature measured by the TMS and by ground sample for four sites is shown in Figure 2.7. The ground temperatures were averaged for the plots measured (as shown in Table 2.4) and plotted against the TMS data averaged over a 3 x 3 pixel matrix centered on the predicted location of our ground sample. The most variant temperature is that for the Rindge/Bare Soil site. Significant variance from the equal temperature line is a result of disparate field sampling times as indicated in Table 2.3. The later sampling time for the Rindge Series resulted in a higher radiant surface temperature than that recorded by the TMS data acquired earlier in the day. The higher TMS temperature and lower ground sample temperature for the vineyard results from the partial canopy cover of the vineyard (approximately 50 percent). The ground temperatures were averaged for foliar measurements only, and the TMS data integrates the surface radiant temperature for both the vineyard and exposed soil. The higher variance for the ground temperature measurements results from sunlit and shaded portions of the canopy being averaged.

Based on this and other investigations, infrared thermometers can be successfully used to estimate surface radiant temperatures for soil survey and management activities.

### 2.1.4. Summary

Based on our preliminary analysis of the TMS data, the following significant results can be reported:

1. The location and width of the TM bands are suitable for detecting differences in selected soil properties.

2. The number of TM spectral bands allows the quantification of soil spectral curve form and magnitude.

3. The spatial and geometric quality of the TMS data allow for the discrimination and quantification of within field variability of soil properties.

Future research activities could include: expanded statistical analysis of the ground sampled radiant temperatures, modeling of the spectral data to predict the relative magnitude of the selected soil properties and integration of other variables such as plant-soil moisture relationships into the modeling process.

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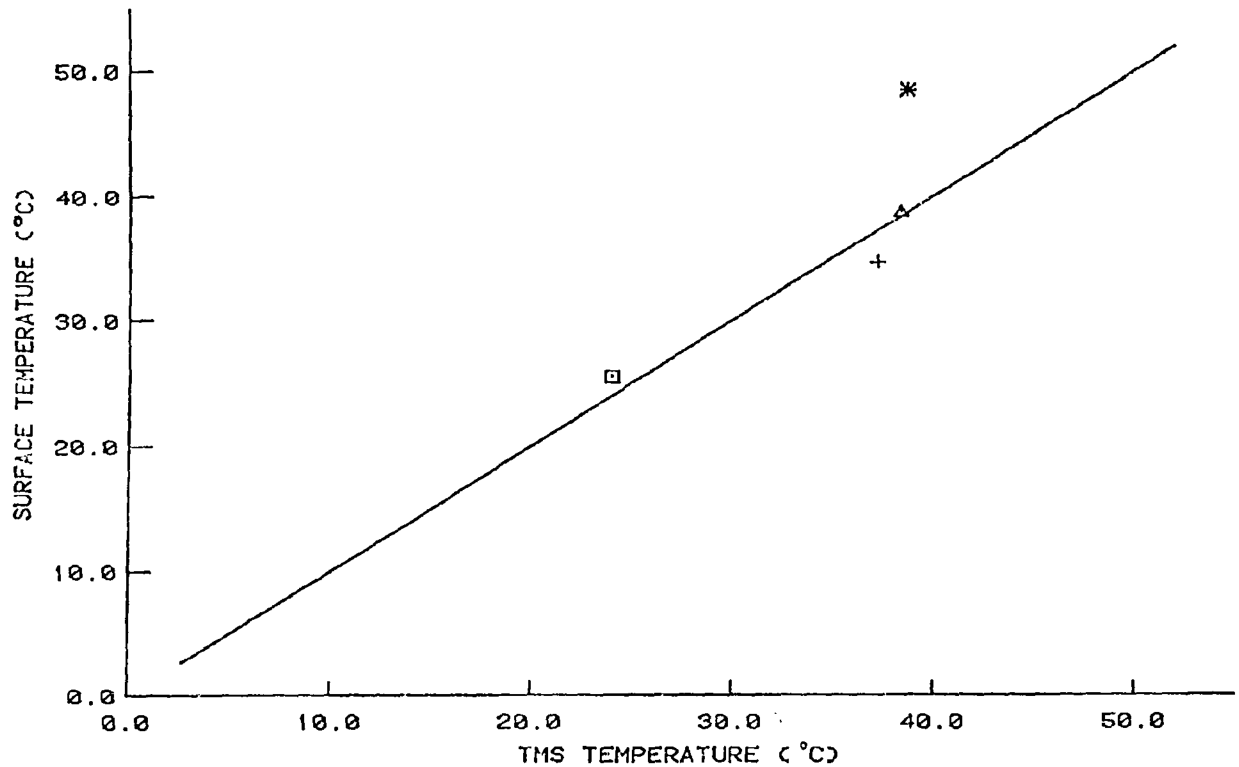


| Symbol | Soil/Surface cover | Surface Temperature $\bar{X}$ | S | CV | TMS Temperature $\bar{X}$ | S | CV |
|---|---|---|---|---|---|---|---|
| △ | Escalon/Bare soil | 38.7 | 0.7 | 1.8 | 38.3 | 1.0 | 2.6 |
| ⊡ | Escalon/Pasture | 25.5 | 1.4 | 5.5 | 24.0 | 0.9 | 3.8 |
| + | Escalon/Vineyard | 34.6 | 11.6 | 33.5 | 37.2 | 1.0 | 2.7 |
| ✳ | Rindge/Bare soil | 48.4 | 0.8 | 1.7 | 38.6 | 0.8 | 2.1 |

Figure 2-7. Relationship between the surface radiant temperature measured by the TMS and ground sample for four sites.

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## 2.2. Multidate Analysis for Crop Characterization

### 2.2.1. Background

Current results on the role of Landsat Thematic Mapper in agricultural crop characterization and inventory are both limited and preliminary. Improved measurement of small targets (fields), separation of plants based on leaf water content, soil moisture characteristics or evapotranspiration and differentiation of species are important topics that the improved spectral and spatial resolution of TM may provide. The Thematic Mapper Simulator sensor flown by NASA/ARC provided the opportunity to investigate some of these topics prior to operational receipt of real Landsat-4 and -5 TM data.

Several types of remotely-sensed data were acquired for portions of the Central Valley during 1982. These data included Thematic Mapper Simulator (TMS) data (twelve channels, including thermal), CIR highflight photography (1:130,000-scale), and Landsat 3 MSS digital data (with associated imagery). Extensive ground data were also collected throughout the 1982 growing season. Some of these observations were also coincident with Landsat satellite overpasses.

The 1983 progress report (Wall et al, 1983), discussed this extensive ground data collection effort initiated by personnel from the RSRP and NASA-Ames Research Center. These data were collected wall-to-wall along Jack Tone Road, east of Stockton, and included such attributes as irrigation codes, cover type, emergence dates, row width and direction, growth stage code, canopy height, surface moisture, and weediness information. This information was used extensively in the work reported on here.

### 2.2.2. Data Processing

Spectral Data

Three dates of Daedalus TMS data were used in this study. These dates were selected because they corresponded to actual TM overpasses and/or they provided the temporal separation necessary to generate meaningful crop spectral/temporal profiles. The dates used were:

9 June 1983
15 July 1983
12 August 1983

The data consisted of seven TMS channels, including a thermal channel. In addition to these raw data, four principal component (PC) bands were calculated from the original raw data channels using VICAR/IBIS software at NASA-Ames. The PC transformation basically ranks the original raw data bands in terms of their potential information content: bands that are highly correlated are therefore given less weight in the calculation of the PC output channels. Seven PC's were initially generated, of which only four contained significant information.

### Field Boundary Overlays

In order to provide statistical summaries and generate profiles of the spectral data for each of the three TMS data sets, fields identified during the ground visits had to be located and labelled within the digital files. The geometric characteristics of the TMS data, which are a result of the relative instability of the aircraft platform, precluded date-to-date registration. Therefore, each date was analyzed independently. The fields selected for analysis were those which were entirely contained within the flightlines of all three dates. Once these fields were identified, they were outlined on each date using an interactive cursor and television screen. This procedure was repeated for all three dates. Table 2.7 gives a breakdown of the fields used by cover type. In all, 162 fields were outlined on each date.

### Field Mean Generation

As part of RSRP's cooperation with NASA-Ames, the goal of this task was to provide Ames personnel with spectral means by crop type so that profiles (by date, by channel) could be generated at that facility. As a result of the boundary definition procedure, each date had associated with it a band of field locations (for the 162 fields). These bands were then used as masks for generating per-field mean spectral response for the TMS and PC channels. These spectral means by date and per channel were then ready for input into further analysis at NASA-Ames.

Subsequent to these analyses, NASA program re-direction has de-emphasized this TMS related research. It is hoped that this work can be resumed at some future time.

Table 2.7. Cover type breakdown for the 162 fields used on all three dates.

| Cover Type | Number of Fields |
| --- | --- |
| corn | 24 |
| alfalfa | 12 |
| sugar beets | 28 |
| tomatoes | 15 |
| dry beans | 10 |
| peppers | 2 |
| pasture | 1 |
| grain stubble | 13 |
| almonds | 6 |
| walnuts | 1 |
| vines | 21 |
| fallow | 2 |
| bare soil | 27 |
| Total | 162 |

## 3. DESIGN OF A MULTIPLE CROP ACREAGE ESTIMATION PROCEDURE FOR THE IDAHO DEPARTMENT OF WATER RESOURCES

Under NASA sponsorship*, the Idaho Department of Water Resources (IDWR) is engaged in the research and development of procedures for use of Landsat data in agricultural water use assessment. One supporting task requires the development of classification and sampling procedures for crop-specific acreage estimation and mapping. Crop data are required for a number of water resources assessment functions in Idaho: (1) IDWR determination of consumptive water use and assessment of the state's agricultural economic base; (2) U.S. Geological Survey computer simulation of streamflow for use in the specification of minimum flows at selected points along the Snake River (Idaho's major agricultural water source); (3) water management by the U.S. Bureau of Reclamation; and (4) potential use in agricultural production reporting and forecasting by the U.S. Department of Agriculture.

The specific objective of the crop type task in 1983 was to specify and evaluate on a set of regional test sites one or more candidate procedures for producing crop acreage estimates and maps. This work was to provide the basis for selection of procedures for use in a large area semi-operational test during a subsequent year. The University of California at Berkeley's role in this effort was to consult, investigate, and advise on experimental design and inventory design requirements in 1983.

The general approach to inventory design specification was to build on previous work, particularly earlier irrigated and crop land studies performed in California (Wall et al. and Idaho (IDWR, 1982). Results from the 1980 Snake River Plain Landsat experiment were to provide specific correlation, cost, and accuracy data for use in procedure specification.

### 3.1. Inventory Design Specification and Definition of Inventory Goals

The first element of any inventory design activity is to obtain the clearest statement of specific estimation and mapping goals possible. IDWR (Anderson, 1983) identified these as being acreage estimates and classification maps for crops or crop groups most important in terms of acreage, consumptive water use, and dollar value.

These target cover type categories included (1) a set

*The NASA-Ames Research Center, Technology Applications Branch's Western Experimental Test & Evaluation Program (WRETE).

consisting of small grains, row crops, pasture, and alfalfa; (2) a group of two high-importance crops: potatoes and sugar beets; and (3) irrigated versus non-irrigated crop land. Acreage estimates for each of these cover types were to be produced by county and for several counties combined. Landsat classification maps showing the specific location of each cover type within the inventory area were also to be provided in an operational system.

Performance constraints attached to these inventory objectives were stated as flexibly as possible, pending results from the 1983 evaluation. However, for purposes of experiment, it was decided to establish an acreage estimate precision (error) goal of +10 percent at the 95 percent level of confidence as an initial standard for each cover category named above. Map accuracy and cost constraints were not established in an absolute sense. However, results from the 1980 Snake River Plain (single Landsat date) study were to be used as a baseline of performance. Candidate procedures were to be implementable on equipment and software available to IDWR (VICAR/IBIS and USDA Editor).

## 3.2. Specification of Appropriate Design Alternatives

The purpose of this step in the design process was to specify a set of candidate procedures potentially capable of meeting the IDWR crop inventory goals. This list of appropriate design alternatives was based on work in previous studies, the experience of the design team, and knowledge of the characteristics of the population to be surveyed. Specifications were made for each of the following system design components: sample frame, measurement, sample allocation, and estimation and mapping.

### Sample Frame

1) Sample unit layout: two phase (Landsat/ground) design with

   a) Option 1: square grid of rectangular sample units covering agricultural strata

   b) Option 2: use USDA sample frame with units of approximately equal size, layed out along man-made or natural boundaries.

   c) Option 3: some composite of Option #1 and Option #2.

2) Sample unit size

   a) Option 1: one of 0.5, 1, 1.5, 2, or 3 $mi^2$ in the case of the rectangular grid

   b) Option 2: approximately 0.5 or 1 $mi^2$ in important agricultural strata if using the USDA sample frame

   c) stratification or grouping of sample units for purposes of later acreage estimation

      i) Option 1: use 1980 Snake River Plain study stratification based on location, crop type mix, and field size.

      ii) Option 2: use new USDA stratification based on crop mix

      iii) Option 3: possible new stratification

3) Sample unit allocation for measurement

   a) Landsat sample phase: complete enumeration in order to eliminate sample variance and enable mapping of entire area.

   b) ground sample phase

      i) Option 1: sample proportional to stratum size for simplicity

      ii) Option 2: allocate sample for ground measurement among strata according to variance/cost optional rules in order to obtain the highest acreage estimate precision for fixed cost

4) Measurement

   a) Ground

      i) Option 1: use windshield-stop & go field-by-field survey to locate/update field boundaries and label fields (or exclusions) as to cover type. Field boundaries to be drawn or checked on acetate sheets covering USGS quadrangle maps using most recently available highflight aerial photography. Field labelling check to be performed for a sample of sample segments.

      ii) Option 2: Option 1 plus use of USDA June Enumerative Survey (JES) sample segment data. JES data to include field boundaries and cover type labels screened for using standard

USDA survey editing procedures, checked later by IDWR using 1983 highflight data.

iii) Option 3: Option 1 or Option 2 plus frequent phenology observations on an independent set of sample (transect) fields within each study site. Transect fields to be used to characterize major crop canopy geometry and field (e.g. moisture) conditions as a function of time during the growing season. This data to be used in establishing an understanding of the physical basis for spectral reflectance recorded by Landsat. Transect field boundary and cover type information to be recorded on USGS quadrangle maps; use of highflight aerial photographs where available to check location.

b) Landsat

i) Option 1: maximum likelihood classification of two or more dates of Landsat data; cover type spectral model definition based on unsupervised clustering of systematic sample of study area; cluster labelling by intersection of cluster map with digitized, registered ground data.

ii) Option 2: Option 1 except that clustering confined to training segments as in standard USDA Editor procedure.

iii) Option 3: Option 1 or Option 2 using at least one date of TM instead of MSS data

iv) Option 4: Option 1 or Option 2 (with MSS data) assisted by maximum likelihood classification of at least one date of TM data

5) Estimation and Mapping

Landsat-ground simple linear regression estimation of acreage by cover type; maps consisting of standard maximum likelihood classification with clusters grouped into categories of interest; output at scale and in hardcopy form desired by IDWR.

Most of these design alternatives represented established techniques, (e.g. ground data collection methods for sample units, maximum likelihood classification of Landsat data, and regression estimation). Classification procedures that would involve the simultaneous use of both TM and MSS data had not, at the time of project initiation, been established or tested.

## 3.3. Culling Alternatives to Obtain Feasible Designs

The candidate alternatives described in the previous section were subjected to a preliminary evaluation to identify those inventory designs capable of meeting IDWR's goals and constraints. The first portion of this evaluation was the primary topic of multicrop procedure development activities during calendar year 1983. Design alternatives remaining at the end of this evaluation activity were to form the basis for a much larger inventory test in a subsequent year.

### 3.3.1. Determination of Size of Sample Unit

Advantages and disadvantages of the various sample frame options were reviewed. Given the cost and information sharing advantages of cooperation with USDA, the second sample layout option was ranked as the preferred alternative. However, its properties for use with remote sensing data had not been established in Idaho - in particular, the relative size of acreage estimate population variance associated with USDA units was unknown. To resolve this question, a simulation experiment was designed in such a way that stratification and sample allocation issues (to be described later) could also be addressed.

Digital Landsat classification map data from the 1980 study was obtained for an approximately 1550 (X) by 1100 (Y) area of primary interest to the IDWR and the USDA. This site occupied a portion of the Snake River Plain (an area roughly centered north of Twin Falls) dominated by wheat, potatoes, alfalfa, beans, corn, and pasture. The digital classmap was input to the U.C. Berkeley Survey Planning Model (SPM) along with a registered version of the 1980 land use stratification. Three sizes of sample units were defined for consideration: (1) a reference, USDA-like 30x27 pixel size representing approximately 1 $mi^2$; (2) a larger 45x45 pixel size representing an area approximately 2.6 $mi^2$. Exact sample unit pixel dimensions were constrained both by the target size and by the desire to divide the test area up into an integer multiple of sample units.

Given these sample unit sizes, the SPM was then used to superimpose each size of sample grid over the Twin Falls study area. Each sample unit was classified to the land use stratum occupying the largest proportion of the sample unit. The proportion of each sample unit occupied by the inventory target cover types described earlier was then simulated by the SPM. This simulation proceeded by first obtaining the count for each Landsat class in each sample unit and then multiplying this count by the proportion of that Landsat class (assumed) to be a given ground cover type. In most cases, Landsat class composition was assumed to be either entirely one target ground cover type or a simple mix of two ground cover types. These simplifying assumptions were necessary in order to obtain a conservative (i.e. is relatively high) estimate of target crop acreage variation among sample units.

Once target crop or cover category proportions had been simulated for each sample unit, between unit sample variance for each such category was computed by land use stratum. These variance data, along with the average proportion of target cover type by stratum, were next submitted to the SPM's non-linear programming module. This module solved for the ground sample size required to achieve user-specified levels of sampling precision for each target ground cover category. Assumptions regarding measurement cost and Landsat-to-ground acreage measurement correlation (by crop type) were also required here. These supporting data (shown in Tables 3.1 and 3.2) were developed using information from the 1980 study.

The resulting SPM sample size and sample size-dependent cost solutions for the Twin Falls data set are shown in Table 3.3 for various assumptions on correlation. These correlations represented guesses concerning the possible strength of Landsat-to-ground relationships resulting from the use of multiple dates of Landsat. In all cases shown, the precision goals were set to at least $\pm 8$ percent of the estimate at the 95 percent level of confidence simultaneously for each of four IDWR target crops.

Results shown in Table 3.3 suggested that sample size-dependent cost requirements to achieve the $\pm 8$ percent error goal are relatively close for the 2.6 and 1 $mi^2$ sizes of sample units. Costs for the correlation sets. The higher cost value associated with this size of unit was due to the significantly larger between-sample unit acreage variation (by crop type) found to exist by SPM simulation. Thus for a given set of Landsat-to-ground correlation values, a much higher ground sample size was required to produce the precision desired.

Based on these results, and the desirability of using an existing sample frame, it was decided to base 1983 survey evaluation activities on the approximately 1 $mi^2$ sample units used by USDA. This action was expected to have the desirable effect of ultimately enabling information and/or inventory task sharing between two agencies (IDWR and USDA) having major interest in Idaho agricultural statistics.

TABLE 3.1. Sample Unit Cost Coefficients Used by the SPM for the 1983 Simulation*

45 x 45 pixel size (~2.6 $mi^2$)

per sample unit measurement cost = \$115

per sample unit travel cost = \$59

30 x 27 pixel size (~1 $mi^2$)

per sample unit measurement cost = \$85

per sample unit travel cost = \$51

15 x 13 pixel size (~.25 $mi^2$)

per sample unit measurement cost = \$67.50

per sample unit travel cost = \$40

*Developed from cost data provided by IDWR (Anderson, 1983).

TABLE 3.2. Alternative Sets of Landsat-to-Ground Cover Type Acreage Correlations Assumed* for the Purpose of SPM Sample Allocation Simulation in 1983.

For All Sampling Strata:

Multiple Crop

| Alt # | Small Grains | Row Crops | Pasture | Alfalfa |
|---|---|---|---|---|
| 1 | .7 | .6 | .4 | .5 |
| 2 | .8 | .7 | .6 | .6 |
| 3 | .9 | .85 | .75 | .8 |

Potatoes

| Alt # | Potatoes |
|---|---|
| 1 | .7 |

Potatoes/Alfalfa Mix

| Alt # | Potatoes/Alfalfa Mix |
|---|---|
| 1 | .5 |
| 2 | .6 |
| 3 | .8 |
| 4 | .9 |

Irrigated Land

| Alt # | Irrigated Land |
|---|---|
| 1 | .6 |
| 2 | .8 |
| 3 | .9 |
| 4 | .95 |

*Based on subjective projection of results from single date Landsat analysis in 1980 to expected multidate Landsat analysis in 1983.

Table 3-3. SPM ground sample allocation and ground sample size-dependent cost for Idaho Study Area #2 (Twin Falls Region North)*.

| | Dimensions of Sample Units in Pixels | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Correlation Set=(.7/.6/.4/.5)*** | | | Correlation Set=(.8/.7/.6/.6) | | | Correlation Set=(.9/.85/.75/.8) | | |
| STRATUM** | 45x45 | 30x27 | 15x13 | 45x45 | 30x27 | 15x13 | 45x45 | 30x27 | 15x13** |
| Large Fields - Lower Snake River Plain | 8 | 14 | 28 | 7 | 12 | 23 | 6 | 9 | 17 |
| Large Fields - Central Snake River Plain | 30 | 48 | 97 | 25 | 38 | 76 | 19 | 28 | 54 |
| Small Fields - Central Snake River Plain | 70 | 102 | 182 | 58 | 82 | 142 | 44 | 59 | 100 |
| Small Fields - Boise Area | 7 | 10 | 16 | 6 | 9 | 13 | 5 | 7 | 10 |
| Mixed Field Sizes - Central Snake River Plain | 13 | 19 | 41 | 11 | 16 | 33 | 9 | 12 | 23 |
| High Field Variation Area | 19 | 33 | 67 | 16 | 27 | 53 | 13 | 20 | 38 |
| Dry Farmed Area | -- | -- | 1 | -- | -- | 4 | -- | -- | 4 |
| Total Units | 147 | 226 | 432 | 123 | 184 | 344 | 96 | 135 | 246 |
| Total Sample Size-Dependent Cost Not Adjusted for Rounding Sample Size Results | 18,515 | 20,946 | 31,089 | 15,621 | 17,215 | 24,982 | 12,355 | 12,829 | 18,109 |

*Allocation necessary to achieve ±8% confidence interval half-width size at the 95% level of confidence simultaneously on small grains, row crops as a group, pasture, and alfalfa.

**These were the 1980 Snake River Plain Study strata; USDA strata could not be used as they were not yet available.

***Landsat-to-ground correlations assumed for small grains, row crops as a group, pasture, and alfalfa respectively, by stratum

### 3.3.2. Sample Unit Layout and Stratification

The decision on sample unit size and sample frame described above fixed the layout (shape and distribution/location) of the units. That is, the layout would be that established by the USDA. The USDA frame also had the advantage of having been recently updated. This was particularly important relative to the way in which the sample units were stratified. The new USDA stratification was more detailed than the former USDA design, thus allowing improved crop acreage variance control (i.e. better control of estimate error). Since sample unit layout was also somewhat dependent on stratum designation, the set of actual sample units was expected to be reasonably efficient for purposes of measurement and estimation of crop and water-related parameters in the areas of interest to IDWR.

Given the above considerations, then, it was decided to also use the USDA stratification as the primary stratification alternative for inventory work commencing in the summer of 1983. However, the option to define and evaluate an alternative (possibly more detailed) stratification scheme was retained. Such an option was considered necessary to address the complete range of local and regional information objectives the IDWR might develop.

### 3.3.3. Sample Unit Allocation for Measurement

Acreage Estimation

In order to determine the approximate number of ground sample units required to estimate IDWR target cover category acreages with reasonable precision, SPM simulation analysis was performed on study areas #1 (Boise region), #2 (Twin Falls region north), and #3 (Blackfoot region). Each of these Snake River Plain study areas was represented by an approximately 1550 point by 1100 line pixel block. Sample unit variances were simulated for cover categories assuming a 30 x 27 pixel (~1 $mi^2$) sample unit size in each case. Since the new USDA stratification (design option #2) was not yet avail able, sample units could only be grouped according to the 1980 study stratification (design option #1). The resulting cover type variance/covariance matrices were then submitted to the SPM non-linear programming package, SUMT, (see Fiacco and McCormick 1968 and Wensel *et al* 1981) along with sample unit population sizes, anticipated Landsat-to-ground correlations (Table 3.2), and anticipated 1 $mi^2$ sample unit measurement and travel costs (Table 3.1). Tables 3.4 through 3.10 present the SPM ground sample size solutions for each set of IDWR crop target cover types. The left-most three numerical columns of Table 3.4 illustrate the decreasing sample requirements (226 units to 135) as

Landsat-to-ground correlation is increased for each of the four major agricultural cover types. A fourth column shows the further decrease introduced when the precision goal (by crop type) is reduced from ±8 percent of the estimate at the 95 percent level of confidence to ±10 percent. This two percent allowable error change causes a 29 percent drop in the number of ground sample units required. Table 3.5 provides a comparison for the same crops among each of the three study sites. Note that except in three cases, different strata occur in each area. Expected ground sampling rates were found to be reasonably close (14.8, 15.6, 21.6 percent) in the High Field Size Variation Stratum where a meaningful comparison between study sites was possible.

Tables 3.6 and 3.7 give the expected ground sample sizes required for potato acreage estimation over a range of precision and correlation levels. Assuming a Landsat-to-ground correlation of .7, Table 3.6 shows that a minimum of 336 sample units would require ground measurement to achieve an allowable error of +10 percent at the 95 percent confidence level (CL). Only 124 units would be required if the error goal was dropped to ±20 percent of the estimate. Table 3.7 illustrates the effect of change in correlation when relatively pure potato spectral classes are combined with spectral classes associated with potatoes but also confused with alfalfa. The number of ground-measured units required ranged from 122 at a correlation of .5 to 46 units at a correlation of .9, given an acreage precision goal of +18 percent at the 95 percent CL. Similar numbers at ±8 percent precision were 386 (r = .5) and 140 (r = .9). The relatively high sample size requirements associated with potatoes resulted from the smaller acreage (relative to that of the four major crop groups) associated with this crop.

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Tables 3-4 through 3-10 follow. Text resumes on page 48.

Table 3-4. SPM solution for ground sample size requirements in Study Area #2 to achieve stated levels of regression estimate precision on Small Grains, Row Crops as a group, Pasture, and Alfalfa.

| 1980 Stratum Appearing in Study Areas | Corr Set=(.7/.6/.4/.5) Precision = ±8% at 95% | Corr Set=(.8/.7/.6/.6) Precision = ±8% at 95% | Corr Set=(.9/.85/.75/.8) Precision = ±9% at 95% | Corr Set=(.9/.85/.75/.8) Precision = ±10% at 95% | Population Size |
|---|---|---|---|---|---|
| Small Fields - Boise Area | 10 | 9 | 7 | 6 | 38 |
| Small Fields - Central Snake River Plain | 102 | 82 | 59 | 40 | 466 |
| Small Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Lower Snake River Plain | 14 | 12 | 9 | 7 | 81 |
| Large Fields - Central Snake River Plain | 48 | 38 | 28 | 20 | 265 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | 1 |
| Large Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Boise Area | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Central Snake River Plain | 19 | 16 | 12 | 9 | 162 |
| High Field Variation Area | 33 | 27 | 20 | 14 | 173 |
| Dry Farmed Area | --- | --- | --- | --- | 1 |
| Small Tributaries Area | --- | --- | --- | --- | 4 |
| Bear Valley | --- | --- | --- | --- | 0 |
| Total | 226 | 184 | 135 | 96 | 1191 |

*Precision stated here as allowable error (confidence interval half-width) at the 95 percent confidence level. Landsat-to-ground correlation set assumptions stated for small grains, row crops, pasture, and alfalfa respectively.

Table 3-5. SPM solutions for ground sample size required to simultaneously achieve stated precision for Small Grains, Row Crops as a group, Pasture, and Alfalfa assuming regression estimation and respective Landsat-to-ground correlations of .8, .7, and .6.

| 1980<br>Stratum Appearing in Study Areas | AREA #1<br>Precision: ±8% at 95% CL | AREA #2<br>Precision: ±8% at 95% CL | AREA #3<br>Precision: ±8% at 95% CL |
|---|---|---|---|
| Small Fields<br>- Boise Area | 63 of 463* | 9 of 38 | ------- |
| Small Fields<br>- Central Snake River Plain | ------- | 82 of 466 | ------- |
| Small Fields<br>- Upper Snake River Plain | ------- | -------- | 110 of 298 |
| Large Fields<br>- Lower Snake River Plain | 0 of 4 | 12 of 81 | ------- |
| Large Fields<br>- Central Snake River Plain | ------- | 38 of 265 | ------- |
| Large Fields<br>- Southern Snake River Plain | ------- | 0 of 1 | ------- |
| Large Fields<br>- Upper Snake River Plain | ------- | -------- | 161 of 343 |
| Mixed Field Sizes<br>- Boise Area | 39 of 347 | -------- | ------- |
| Mixed Field Sizes<br>- Central Snake River Plain | ------- | 16 of 162 | ------- |
| High Field Variation Area | 19 of 128 | 27 of 173 | 25 of 116 |
| Dry Farmed Area | ------- | -------- | 13 of 78 |
| Small Tributaries Area | 0 of 6 | 0 of 1 | ------- |
| Bear Valley | ------- | -------- | 0 of 8 |
| Total | 121 of 948 | 184 of 1191 | 309 of 843 |

* X of Y, where X = ground sample size(e.g. 63) and Y = population size (i.e. total number of sample units available).

Table 3-6. SPM solution for ground sample size requirements in Study Area #2 to estimate Potato acreage within stated levels of precision, assuming a Landsat-to-ground correlation of .7.

| 1980 Stratum Appearing in Study Areas | Precision=±20% at 95% | Precision=±18% at 95% | Precision=±10% at 95% | Precision=±8% at 95% | Population Size (pixel limits) |
|---|---|---|---|---|---|
| Small Fields - Boise Area | 7 | 8 | 14 | 18 | 38 |
| Small Fields - Central Snake River Plain | 27 | 32 | 75 | 97 | 466 |
| Small Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Lower Snake River Plain | 20 | 24 | 55 | 71 | 81 |
| Large Fields - Central Snake River Plain | 40 | 48 | 114 | 147 | 265 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | 1 |
| Large Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Boise Area | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Central Snake River Plain | 18 | 22 | 49 | 63 | 162 |
| High Field Variation Area | 12 | 13 | 29 | 37 | 173 |
| Dry Farmed Area | --- | --- | --- | --- | 1 |
| Small Tributaries Area | --- | --- | --- | --- | 4 |
| Bear Valley | --- | --- | --- | --- | 0 |
| Total | 124 | 147 | 336 | 433 | 1191 |

Table 3-7. SPM solution for ground sample size requirements in Study Area #2 to achieve stated levels of regression estimate precision on a combination of Potatoes and a Potatoes/Alfalfa Mix class.

| 1980 Stratum Appearing in Study Areas | Prec=18% r=.5 | Prec=18% r=.6 | Prec=18% r=.8 | Prec=18% r=.9 | Prec=8% r=.5 | Prec=8% r=.6 | Prec=8% r=.8 | Prec=8% r=.9 | Population Size |
|---|---|---|---|---|---|---|---|---|---|
| Small Fields - Boise Area | 6 | 6 | 5 | 4 | 14 | 13 | 10 | 7 | 38 |
| Small Fields - Central Snake River Plain | 30 | 26 | 16 | 10 | 98 | 89 | 60 | 36 | 466 |
| Small Fields - Upper Snake River Plain | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| Large Fields - Lower Snake River Plain | 17 | 15 | 10 | 7 | 54 | 49 | 33 | 21 | 81 |
| Large Fields - Central Snake River Plain | 37 | 32 | 20 | 12 | 122 | 111 | 74 | 45 | 265 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | --- | --- | --- | --- | 1 |
| Large Fields - Upper Snake River Plain | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Boise Area | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Central Snake River Plain | 22 | 19 | 12 | 8 | 70 | 64 | 43 | 27 | 162 |
| High Field Variation Area | 10 | 9 | 7 | 5 | 28 | 26 | 18 | 12 | 173 |
| Dry Farmed Area | --- | --- | --- | --- | --- | --- | --- | --- | 1 |
| Small Tributaries Area | --- | --- | --- | --- | --- | --- | --- | --- | 4 |
| Bear Valley | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| TOTAL | 122 | 107 | 70 | 46 | 386 | 352 | 238 | 148 | 1191 |

*"Prec" means precision or allowable error at the 95% level of confidence

r = assumed Landsat-to-ground correlation

Table 3-8. SPM solution for ground dample size requirements in Study Area #2 to achieve stated levels of regression estimate precision on Irrigated agricultural acreage

| 1980 Stratum Appearing in Study Areas | Prec=10% r=.7 | Prec=10% r=.8 | Prec=10% r=.9 | Prec=8% r=.7 | Prec=8% r=.8 | Prec=8% r=.9 | Population Size |
|---|---|---|---|---|---|---|---|
| Small Fields - Boise Area | 1 | 1 | 1 | 1 | 1 | 1 | 38 |
| Small Fields - Central Snake River Plain | 73 | 54 | 31 | 105 | 79 | 46 | 466 |
| Small Fields - Upper Snake River Plain | --- | --- | --- | --- | --- | --- | 0 |
| Large Fields - Lower Snake River Plain | 1 | 1 | 1 | 4 | 4 | 1 | 81 |
| Large Fields - Central Snake River Plain | 37 | 28 | 16 | 53 | 40 | 24 | 265 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | --- | --- | 1 |
| Large Fields - Upper Snake River Plain | --- | --- | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Boise Area | --- | --- | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Central Snake River Plain | 10 | 8 | 6 | 13 | 10 | 7 | 162 |
| High Field Variation Area | 17 | 13 | 9 | 24 | 18 | 12 | 173 |
| Dry Farmed Area | --- | --- | --- | --- | --- | --- | 1 |
| Small Tributaries Area | --- | --- | --- | --- | --- | --- | 4 |
| Bear Valley | --- | --- | --- | --- | --- | --- | 0 |
| Total | 139 | 105 | 64 | 200 | 152 | 91 | 1191 |

*Prec = precision or allowable error at 95% level of confidence
r = assumed Landsat-to-ground correlation

Table 3-9. SPM solution for ground sample size requirements in Study Area #1 to achieve regression Irrigated acreage estimate precision of ±8% at the 95% Level of Confidence.

| 1980 Stratum Appearing in Study Areas | r = .7 | r = .8 | r = .9 | r = .95 | Population Size |
|---|---|---|---|---|---|
| Small Fields - Boise Area | 11 | 9 | 6 | 1 | 463 |
| Small Fields - Central Snake River Plain | --- | --- | --- | --- | 0 |
| Small Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Lower Snake River Plain | --- | --- | --- | --- | 4 |
| Large Fields - Central Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Upper Snake River Plain | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Boise Area | 8 | 7 | 5 | 1 | 347 |
| Mixed Field Sizes - Central Snake River Plain | --- | --- | --- | --- | 0 |
| High Field Variation Area | 5 | 4 | 1 | 1 | 128 |
| Dry Farmed Area | --- | --- | --- | --- | 0 |
| Small Tributaries Area | --- | --- | --- | --- | 6 |
| Bear Valley | --- | --- | --- | --- | 0 |
| Total | 24 | 20 | 12 | 3 | 948 |

r = assumed Landsat-to-ground correlation coefficient

Table 3-10. SPM solution for ground sample size requirements in Study Area #3 to achieve regression irrigated acreage estimate precision of ± 8% at the 95% Level of Confidence.

| 1980 Stratum Appearing in Study Areas | r = .7 | r = .8 | r = .9 | r = .95 | Population Size |
|---|---|---|---|---|---|
| Small Fields - Boise Area | --- | --- | --- | --- | 0 |
| Small Fields - Central Snake River Plain | --- | --- | --- | --- | 0 |
| Small Fields - Upper Snake River Plain | 10 | 8 | 1 | 1 | 298 |
| Large Fields - Lower Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Central Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Southern Snake River Plain | --- | --- | --- | --- | 0 |
| Large Fields - Upper Snake River Plain | 14 | 11 | 1 | 1 | 343 |
| Mixed Field Sizes - Boise Area | --- | --- | --- | --- | 0 |
| Mixed Field Sizes - Central Snake River Plain | --- | --- | --- | --- | 0 |
| High Field Variation Area | 7 | 6 | 1 | 1 | 116 |
| Dry Farmed Area | 6 | 5 | 1 | 1 | 78 |
| Small Tributaries Area | --- | --- | --- | --- | 0 |
| Bear Valley | --- | --- | --- | --- | 8 |
| Total | 37 | 30 | 4 | 4 | 843 |

r = assumed Landsat-to-ground correlation coefficient

SPM sample size solutions for irrigated acreage estimation are shown in Tables 3.8 through 3.10. Inspection of these tables shows that significant sample size requirements appear to be confined to three or four strata in each study area. In an operational situation, however, each stratum should be assigned an absolute minimum of four sample units to give at least one degree of freedom. Moreover, a minimum ground sample size of ten would actually be preferred in order to produce reasonably stable estimates. With this upward adjustment, the overall ground sample size requirement for irrigated acreage in Area #2 (assuming r = .8, precision = +8 percent at the 95 percent CL would be close to that required for acreage estimation in the four crop group example in Area #2 (Table 3.4)--when r was assumed to be .8/.7/.6/.6. A similar comparison in Areas #1 and #3 (Tables 3.9 and 3.10 versus Table 3.5) shows that ground sample size requirements for irrigated acreage estimation would be significantly lower than for crop group acreage estimation. Note again, by reference to Table 3.8, the significant increase in sample size required when precision requirements were changed by only two percent (i.e. from 10 percent to 8 percent).

## Crop Group Accuracy Estimation

A calculation was also performed to determine the group sample size required to estimate accuracy for small grains, row crops as a group, alfalfa, and pasture, each to specified precision. This was accomplished using a procedure designed by Card (1982) on a stratified basis. 1980 statistics for all three study areas were pooled in order to give a sample size estimate by crop over the entire Snake River Plain. The resulting estimated ground sample size to estimate accuracy to within ± 5 percent of the estimate, 95 times in 100 (assuming normality) was 51 units for small grains, 61 units for row crops as a group, 97 units for alfalfa, and 59 units for pasture.

## Proportional vs. Optimal Allocation Considerations

Sample size requirements reported earlier for acreage estimation assumed optimal allocation among land use (sampling) strata. Optimal allocation in this case assumed that ground units were allocated to strata roughly proportional to the product of stratum size and between-sample-unit-variance, and inversely proportional to the square root of their relative stratum sample unit-dependent costs. Optimal allocation is expected to produce the highest acreage-estimate precision for cost invested.

An important alternative to optimal allocation is proportional allocation of units to strata for ground measurement. In this case, total ground sample size is allocated to strata in direct proportion to the size of those strata. While this procedure is expected to produce lower precision for fixed cost on average, it does have two important advantages. First, it is simple to implement, especially if selection of units within strata is with equal probability. Second, under the assumption of equal probability sample unit selection, it allows relatively unbiased estimation of other parameters than those for which the original allocation was designed. Thus if one wished to evaluate both acreage estimate precision and classification accuracy, and/or also wished to do so for cover types not considered at the time of the original sample allocation, then a proportional, equal probability of selection allocation would enable a relatively uncomplicated analysis. This would not be true of optimal allocation. Rather complicated adjustments to variance estimates would be required in the optimal allocation case.

Since the ground sample allocation in Idaho was to serve a number of analyses, proportional allocation was selected as the preferred alternative. This meant that the sample sizes reported earlier for acreage estimation had to be considered liberal estimates (that is, potentially low). This fact was known in advance and not considered a problem. Sample sizes reported for accuracy estimation, on the other hand, had been computed under the assumption of proportional allocation to strata.

Decision on Final Ground Sample Allocation for 1983

The sample size calculations and allocation method considerations were used as a background context when the final decision was made on actual ground sample allocation. Given the desirability of using the USDA sample frame, final sample size and allocation would be largely constrained by the USDA allocation method and budget for acquiring ground sample units. Some flexibility existed, however, for the IDWR to supplement this ground sample size as necessary for purposes of this experiment.

It was decided that the USDA method of allocation was reasonably suitable for addressing both acreage estimation and accuracy estimation objectives. While not proportional, the USDA method of selecting units produced a spatial spread of sample units considered adequate for generating relatively reliable information concerning regression parameters and classification accuracy.

This was, however, not true for ground sample size. Only a relatively small number of USDA sample units (approximately 10 to 20) were scheduled for measurement in each study area. A compromise had to be made between experimental precision objectives and available budget. IDWR recommended, and USDA agreed, to increase (by a factor of 30 to 40 percent) its ground sample size in Area #2 (Twin Falls north). This change allowed the use of independent Landsat spectral model training and test sets, though of a minimum size. It would also provide a sample size large enough to provide relatively meaningful estimates of regression parameters. This doubling was to be achieved by sending USDA enumerators to sample units which had been subject to ground measurement in previous years, but had since been rotated out of the active sample.

USDA sample size was left as planned in Areas #1 and #3. The IDWR was to obtain additional ground sample segment measurements in these areas if its budget permitted. As a consequence, 1983 data from these areas would likely only be used for non-independent test set classification accuracy assessment.

### 3.3.4. Specification of Measurement Procedures

Ground Measurements

The decision to use the USDA sample frame and use primarily USDA ground data, automatically selected for either Option #2 or Option #3. (See pages 32 & 33). Periodic field phenology data was considered to be too expensive to obtain during 1983. This then also eliminated option #3.

The remaining Option #2 ground measurement procedure was centered around the use of standard USDA field enumeration data. IDWR proposed, and USDA agreed, to supplement the standard USDA information with crop canopy and irrigation practice information of use to IDWR. Any ground sample unit data collected by IDWR (on supplementary segments) was to use the windshield/stop and go technique (described in Option #1) originally developed for the 1980 study.

Both USDA and IDWR field boundary and crop label data were to be transferred as accurately as possible to 7-1/2' quadrangle sheets (or acetate overlays). These field data were then to be digitized and registered to the Landsat data for use in classification and acreage estimation. Data error checks were to be made before and after digitization.

Field measurement procedure recommendations were subsequently checked during a week visit to all three study sites during July 1983.

Landsat Measurement

No experimentation was performed relative to this design consideration prior to analysis of 1983 data. Relative to the 1983 data set, the standard USDA Editor approach (Landsat measurement Option #2) was selected for use. This approach involves crop spectral model definition using fields from sample segments only; this is followed by maximum likelihood classification of Landsat data for both sample segments and the remaining agricultural area of interest.

The USDA Editor approach was selected for the following reasons. First it was desirable to use the USDA system in order to enhance the possibility of later federal-state Landsat-related sharing. Second, this approach was considered a satisfactory methodology for providing a reasonable indication of expected crop classification accuracy and Landsat-to-ground correlation. In contrast, systematic spectral reflectance sampling, clustering, and cluster labelling was considered relatively experimental.

Landsat measurement options #3 and #4 involving the use of TM data were dropped from consideration due to the lack of TM data.

### 3.3.5. Idaho 1983 Experiment Status

Thus by mid-1983 an experiment had been defined and initiated based on a series of design considerations and simulation experiments. The inventory design to be tested was based on the use of the USDA/SRS sampling frame in three study areas on the Snake River Plain, with sample units averaging approximately one square mile in size. Sample unit boundaries were defined according to USDA procedures to fall along natural or man-made features (e.g. roads, fencelines, etc.). In one study area (Twin Falls north), the standard USDA ground sample size was supplemented with additional sample units to allow for independent Landsat classifier training and testing, and to enable a meaningful test of acreage estimation procedures.

All sample units, with or without corresponding ground data, were to be subject to crop type classification using a standard multidate MSS processing approach (that of the USDA Editor system). Estimates of classification accuracy were to be obtained for all target crop types or groups on all study areas. Regression estimates of crop acreage, variance, and Landsat-to-ground correlation were also to be obtained for the Twin Falls study area as a whole, and for individual counties within that area.

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## 4. COMPUTER SOFTWARE DEVELOPMENT AND COOPERATIVE COMPUTING

### 4.1. Peditor Project

Peditor is a USDA and NASA-sponsored programming project to rewrite major portions of the existing EDITOR software system. The EDITOR code had been developed over several years by a number of programmers for the purpose of producing estimates of cover type acreage using Landsat digital data and registered ground data files. Although it works well in general, it contains a number of serious problems that affect its potential widespread distribution and use. The major problems include lack of transportability and difficulity of maintenance. The Peditor project was initiated to solve these two problems by producing new versions of specific parts of the EDITOR system. This new system, called Peditor, would be much easier to maintain, and would be designed to be implemented on a variety of computer systems.

UCB programming personel were involved with the Peditor project from the early days. UCB worked closely with Ames Research Center in discussions regarding the design of the Peditor system, including what type of computer systems would be used, what operating system or systems would be supported, and which programming language would be most appropriate. These discussions took several months, with USDA also taking part in several of them.

Once the design questions were settled coding began. The programming language chosen for Peditor was Pascal, and the initial implementation of the Peditor modules was to be on the Midas computer at Ames. The first coding efforts involved writting and debugging the two libraries prmlib and paslib. The prmlib would contain machine dependent code, while the paslib would include various utility routines written in Peditor Pascal. UCB staff wrote a substantial part of the paslib library, while Ames personel implemented the prmlib and wrote the Pascal preprocessor. Gary Angelici and Linda McAllister joined the Peditor programming staff during this phase.

When the libraries and the pre-processor were completed the coding of the applications modules began. USDA had specified 28 modules to be written in the first phase. UCB was assigned four modules: ASMA, CATED, EXTENT and IDENT. All 28 modules were completed either before or just after the specified due dates. During this time the libraries were improved and adjusted as experience with them increased.

In the current phase of the Peditor project several new modules have been specified, as well as continuing efforts to test and debug the modules of the first applications phase. UCB programmers have responsibility for two modules in this phase. One is a new module called STATPLOT, the other is a conversion of the EDITOR module CORREC. These modules are due to be completed on March 15, 1985. The CORREC module is on schedule while the STATPLOT module has fallen about two weeks behind.

## 4.2. Cooperative Computing

A further area of cooperation involves sharing computer processing capabilities in relation to satellite-based research common to both RSRP and NASA/ARC. This processing included sharing the use of the MIDAS systems at both institutions, preparation of data sets on the RSRP Nova-840 system for use by both groups and coordination of interactive and batch processing using the EDITOR software located at Bolt, Beranek and Newman in Boston and accessed by phone lines.

# 5. MIDAS HARDWARE DEVELOPMENT

## 5.1. Ames Hardware Accomplishments

Personnel at NASA/Ames and the RSRP are currently developing a microcomputer-based image analysis system that will eventually serve the needs of research being conducted at the two installations. The overall performance of the system at NASA/Ames was satisfactory in the initial stage of software and hardware development. It was required, however, that the systems at Ames become fully operational and that system reliability be increased. To help achieve this, personnel from RSRP were engaged in solving a number of problems affecting system reliability at Ames. These problem and their resolutions are listed in the paragraphs below.

The system using a 160Mbyte disk drive repeatedly failed to "boot-up" properly. The problem was traced to two items. One was a faulty cable assembly used to connect the disk drive to the controller inside the multibus chassis and the other problem was a defective integrated circuit contained on the MC68000 board. Both items were corrected and the disk drive now operates properly.

Operation of the color graphics devices connected to the image analysis system would intermittently crash the operating system. Again, two problems existed and were corrected. The first was an intermittent cable assembly, and the second was the discovery of a design defect in the color graphics device. The manufacturer was contacted in the second case and a major upgrade of the color graphics devices was required. With this upgrade the defect was corrected and the devices operate properly.

Routine magnetic tape to disk transfer would also crash the operating system on several of the systems. This problem was traced to defective MC68000 boards on the systems at Ames. As a result, the boards at Ames have been replaced with the next revision of the MC68000 boards that were available. Tape transfers now no longer cause problems on the Ames systems.

An eight port multiplexor board necessary for low-speed outside networking and required for the addition of user terminals to the Ames system would not function. This problem was traced to the Ethernet software purchased by Ames. It is apparently incompatible with the eight port board. The manufacturer of the software has promised (but not yet delivered) the next revision of software that will be able to function with the eight port board. It was recommended by RSRP personnel that another manufacturer be contacted for software that is known to operate properly.

It was determined that the controller used to drive the color graphics device could interfere with proper system operation due to some timing constraints of the system as configured. The MC68000 boards (the working revisions) were modified to correct this possible timing difficulty.

NASA/Ames was also involved in integrating an image analysis system for the USDA in Washington, D.C. Upon delivery of the completed system, personnel from RSRP traveled to Washington and successfully installed the system for USDA. This included some initial training of the personnel in Washington and verification of proper system operation.

## 5.2. Hardware Accomplishments and Acquisitions at U.C. Berkeley

Continued development and refinement of MIDAS, including investigating the flexibility of the architecture to accept a wide variety of microcomputers is of special interest to both NASA/ARC and the RSRP. The integration of a SUN Microsystems microprocessor as the basic computer is particularly relevant since the recent NASA-sponsored workshop on scientific workstation development showed that many other groups currently have or are planning to purchase a SUN System. In August, 1984, the RSRP proposed to purchase a SUN Microsystem Model 2/120FS MC 68010 CPU to integrate with the RSRP MIDAS. Other equipment was also purchased to bring the RSRP MIDAS up to full operating capability in order to promote cooperative software testing and development.

The major equipment purchase was the Raster Technology model 1/25 graphics display system. This consists of the R.T. 1/25, an IKON DMA multibus interface, a Conrac 19 inch RGB monitor, and a Summagraphics 12 inch digitizing tablet for cursor positioning. All of these pieces have been received and have been installed on the RSRP MIDAS. The addition of this graphics capability has made the RSRP MIDAS fully operational.

In addition to the above-mentioned acquisitions for the MIDAS, the purchase of a SUN microcomputer system, including the necessary disk controller to allow the SUN to interface to the in-house 160 Mbyte Winchester disk subsystem has been purchased. Both of these items were received in March, 1985, but as of yet have not been fully tested.